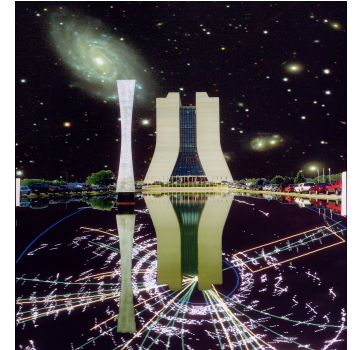


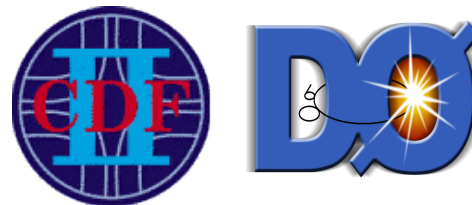
QCD (Jets, W/Z+jets, etc...) at the Tevatron



M. Martínez-Pérez



ICREA/IFAE-Barcelona



Results from CDF & DØ Collaborations



Hadron Collider Physics Symposium, HCP2010,
August 2010, Toronto (Canada)

Outline

- Tevatron, CDF/D0
- Inclusive Jet Production
- Mutijet Production
- W/Z+jets Production
- Photon(s) Production
- Final Remarks



Many interesting results not covered

- B-jet Production
- Hard Diffraction
-



Tevatron

Chicago



$$\sqrt{s} = 1.96 \text{ TeV}$$



Booster

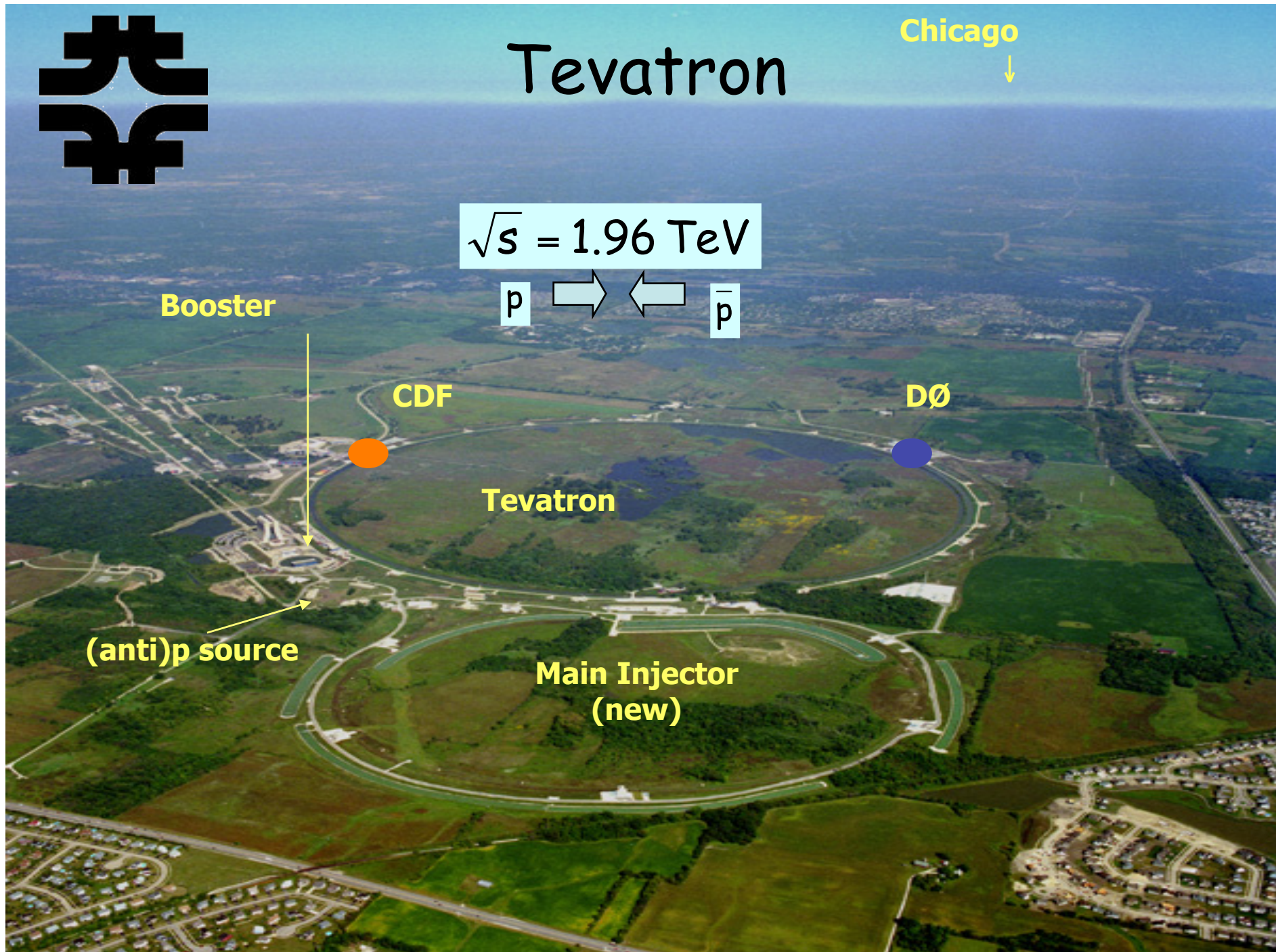
CDF

DØ

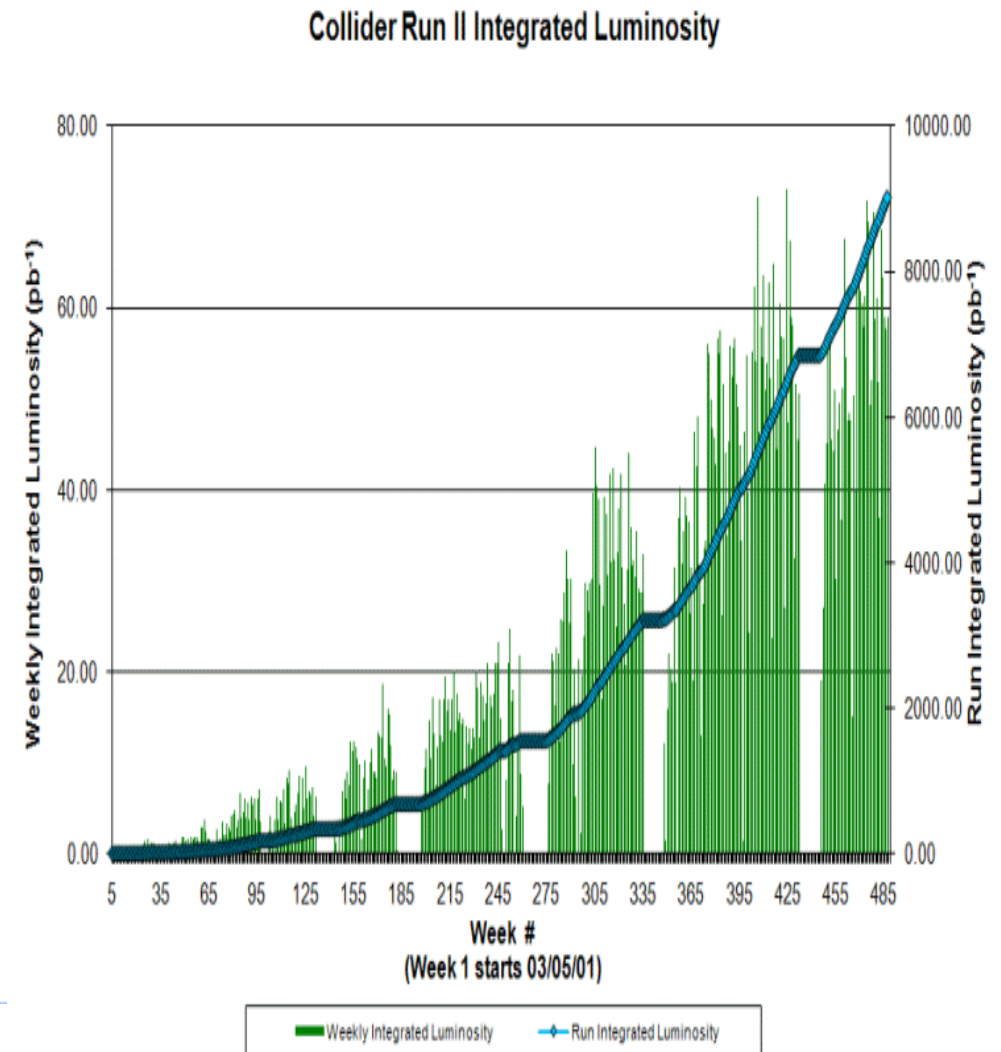
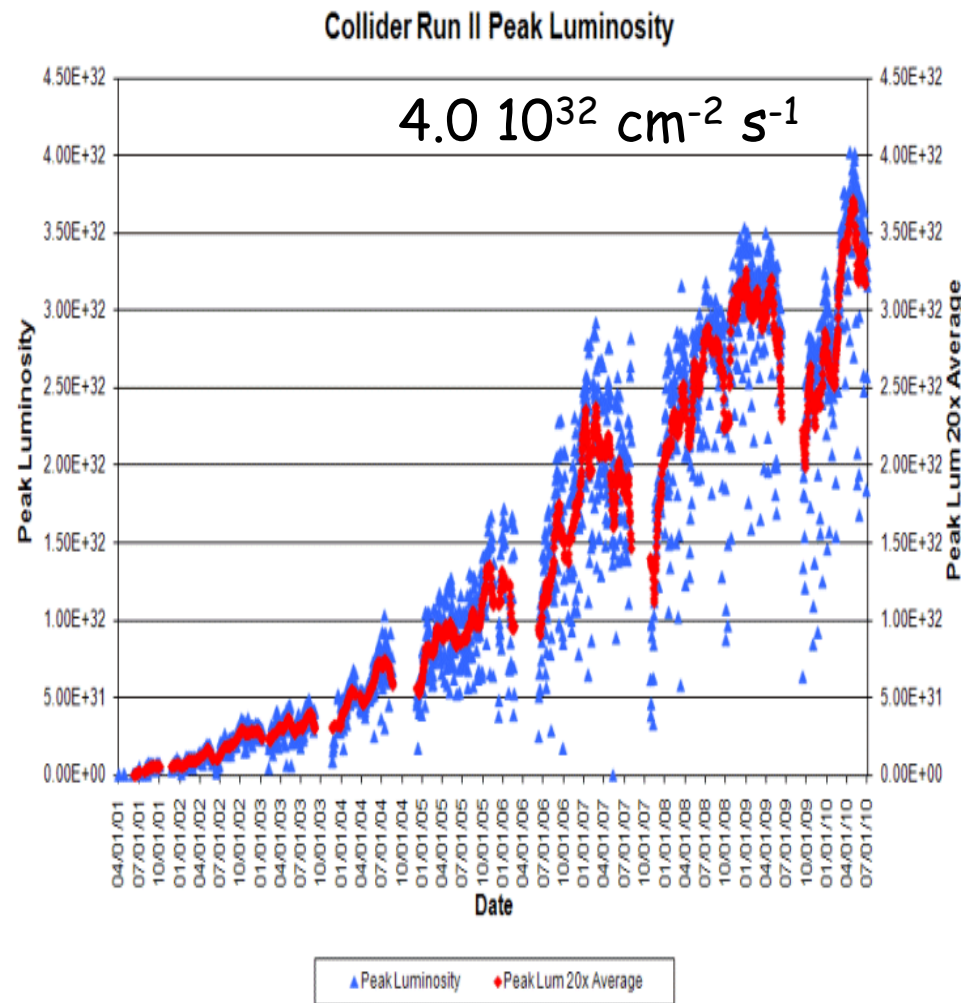
Tevatron

(anti)p source

Main Injector
(new)

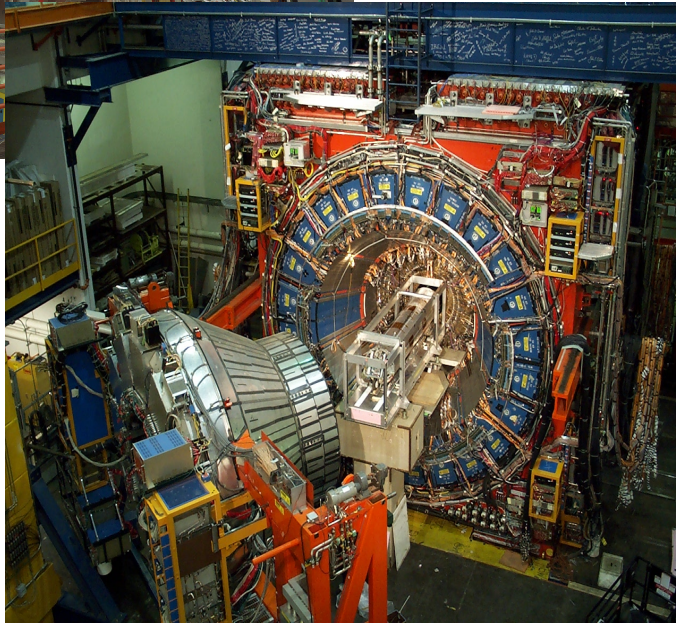


Tevatron Performance

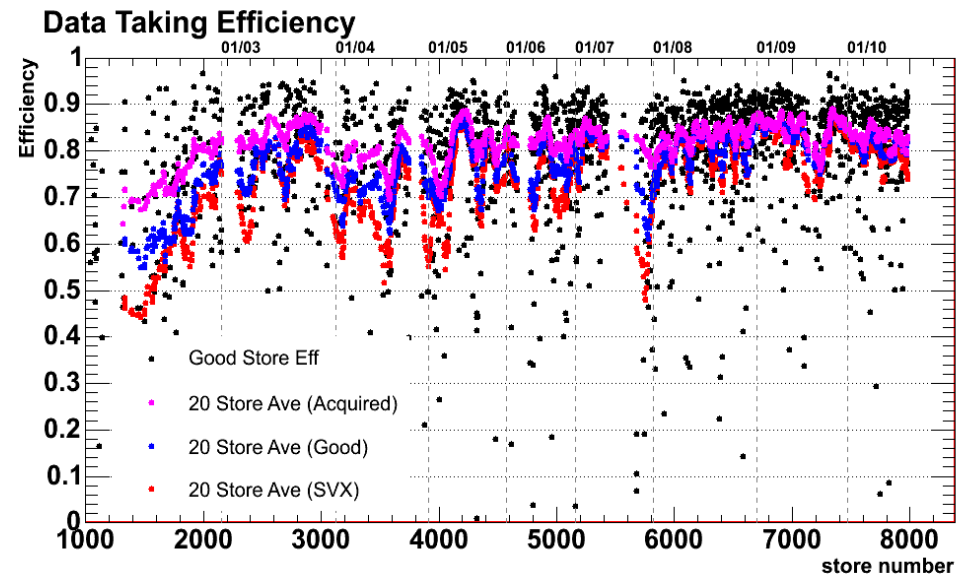
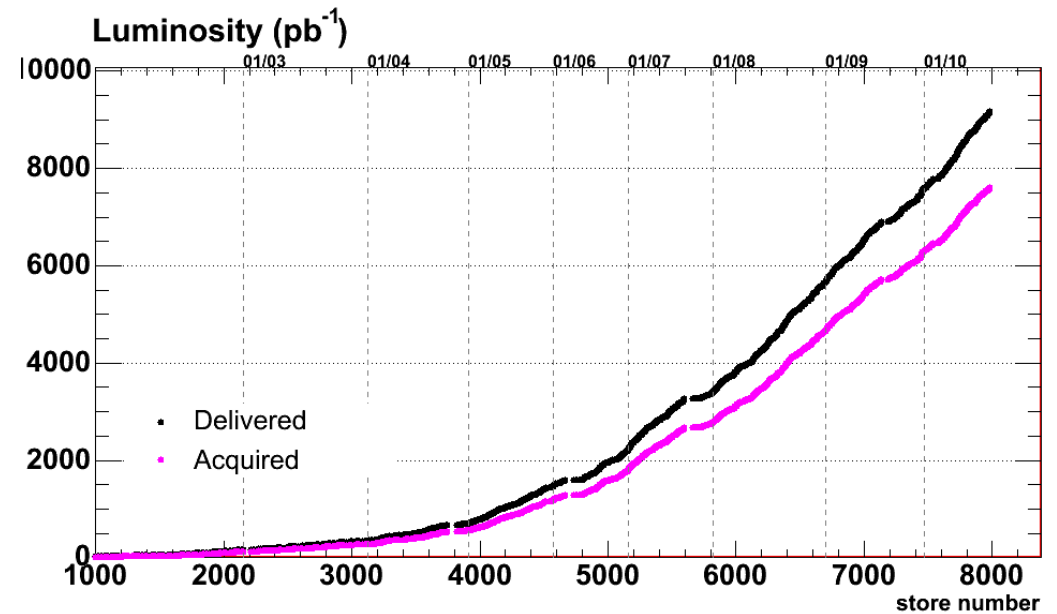


Tevatron delivered $> 9 \text{ fb}^{-1}$
($\sim 12 \text{ fb}^{-1}$ expected by end Run II) (Run I : 120 pb^{-1})

CDF/DO in Run II



Experiments have already
collected $> 7 \text{ fb}^{-1}$ on tape



**CDF/DO operating well recording
physics quality data with
very high efficiency ($\sim 85\%$)**

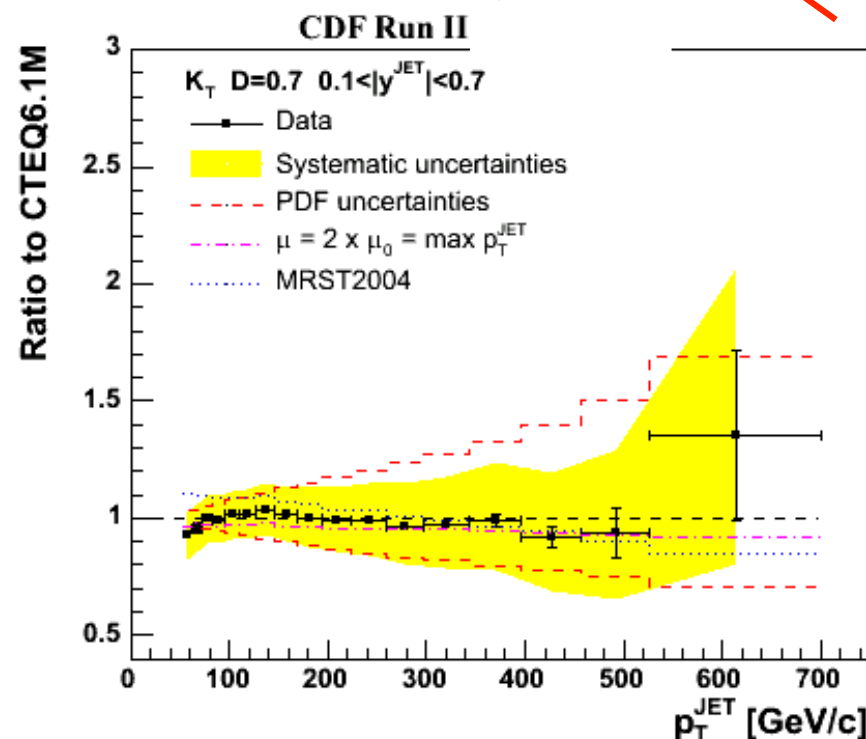


Inclusive Jet Production

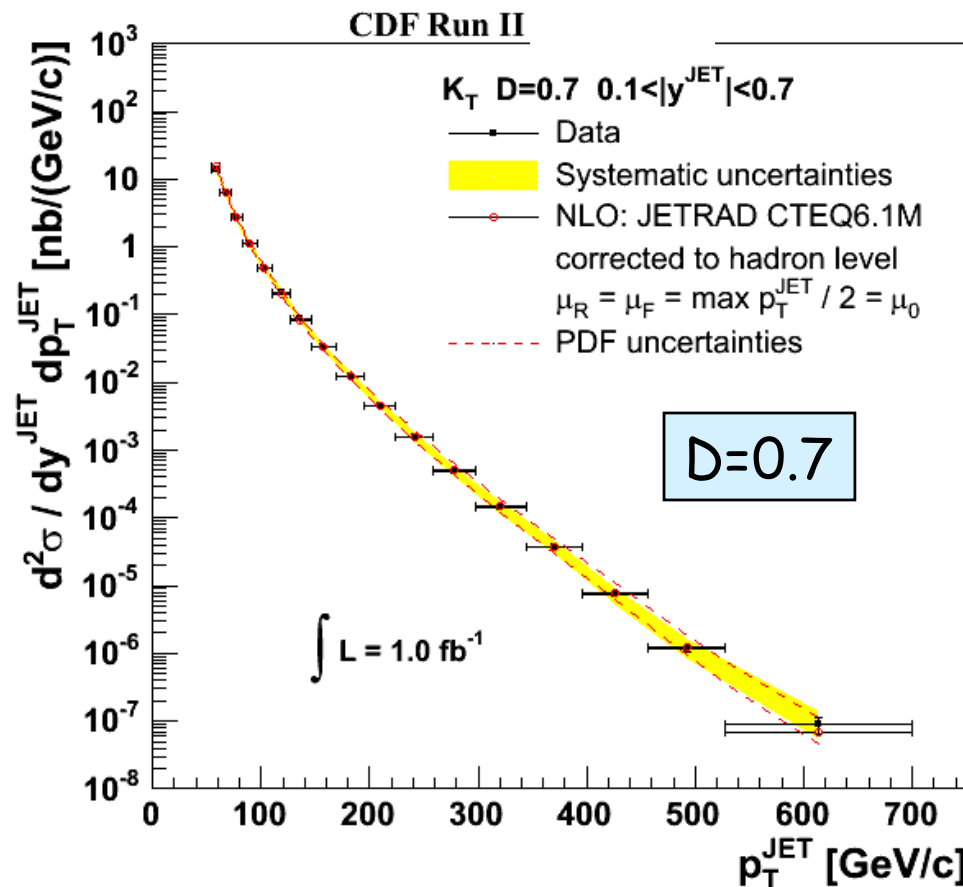
- Inclusive K_T algorithm

$$d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) \frac{\Delta R^2}{D^2}$$

$$d_i = (p_{T,i})^2$$



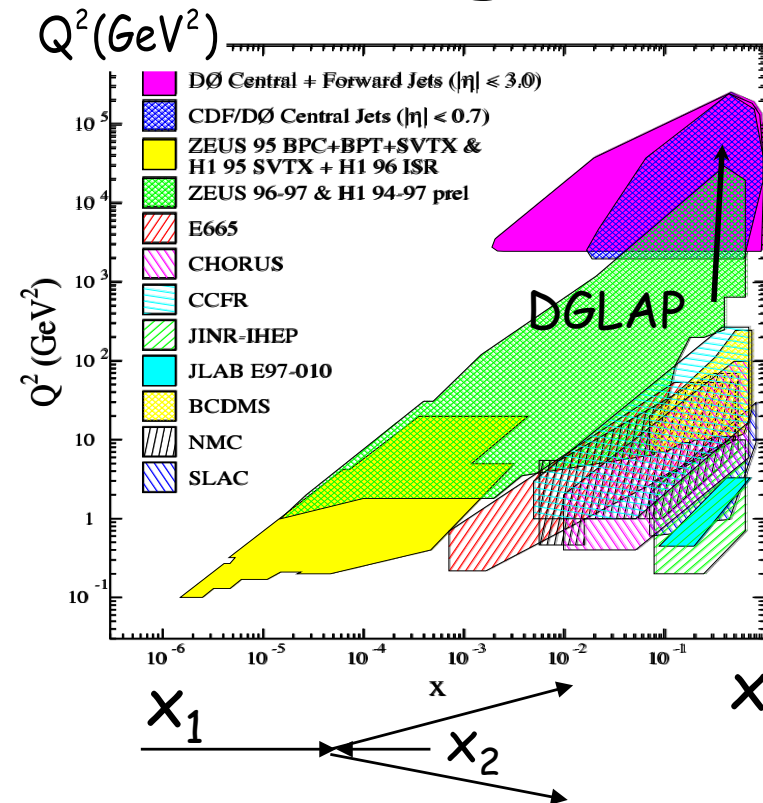
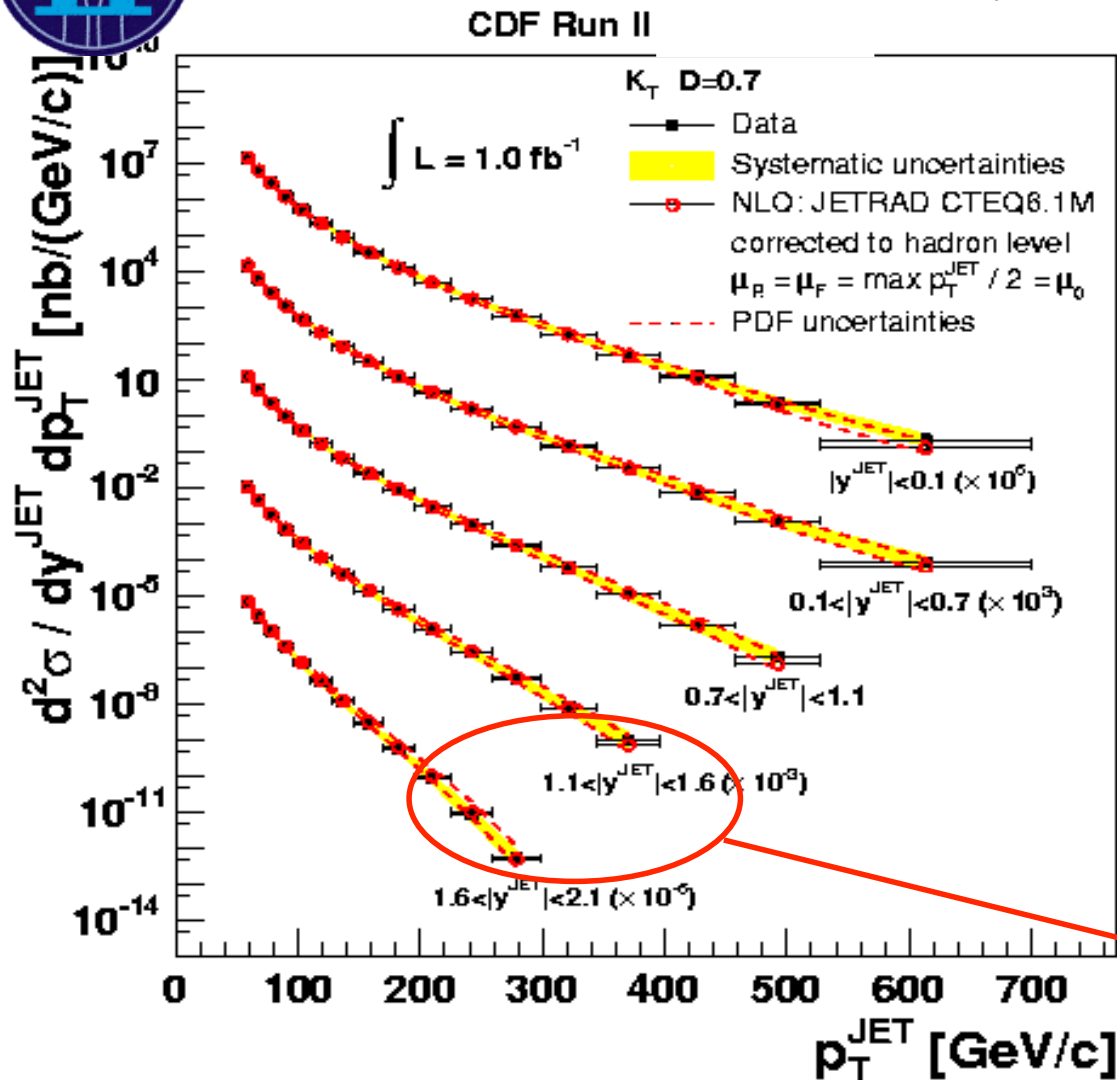
NLO pQCD is corrected for
Hadronization & Underlying Event
(this is important at low Pt)



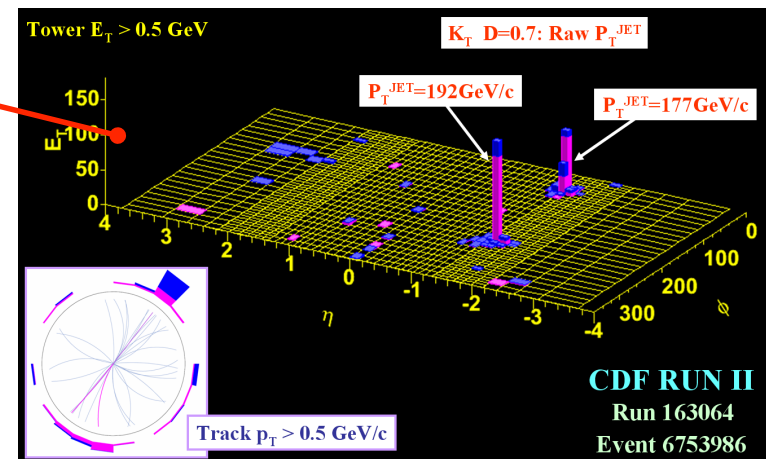
- Good agreement Data vs Theory
 - Data uncertainty \rightarrow 2-2.7% e-scale
 - pQCD uncertainty \rightarrow PDFs
- K_T robust in pp collisions



Measurement in five $|\gamma_{\text{jet}}|$ ranges

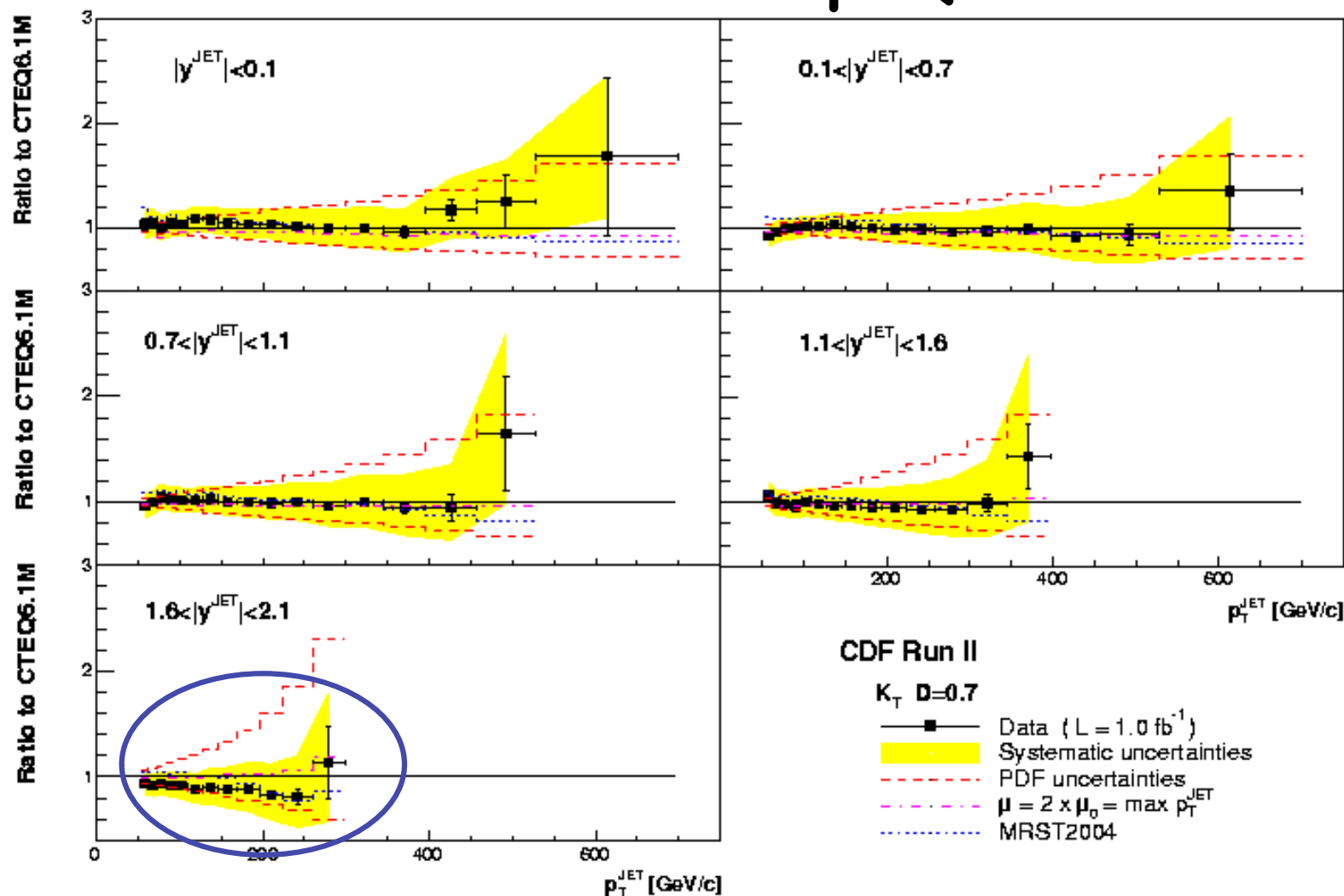


Forward jet measurements further constrain the gluon PDF in a region in p_T where no new physics is expected





Ratio Data/pQCD NLO



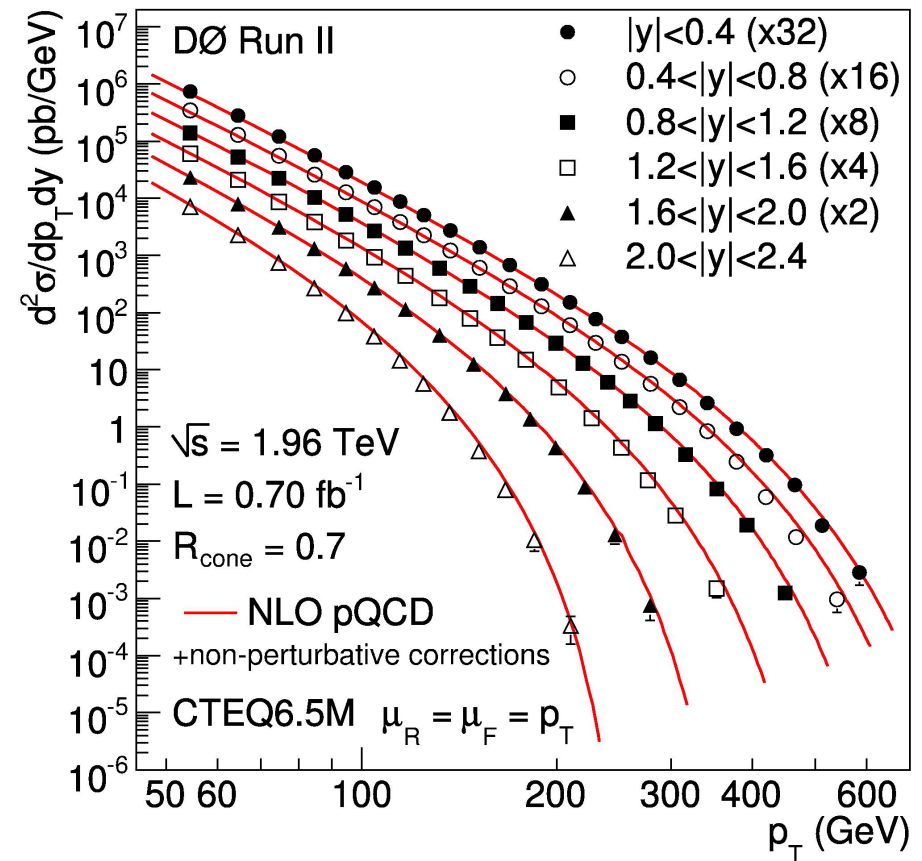
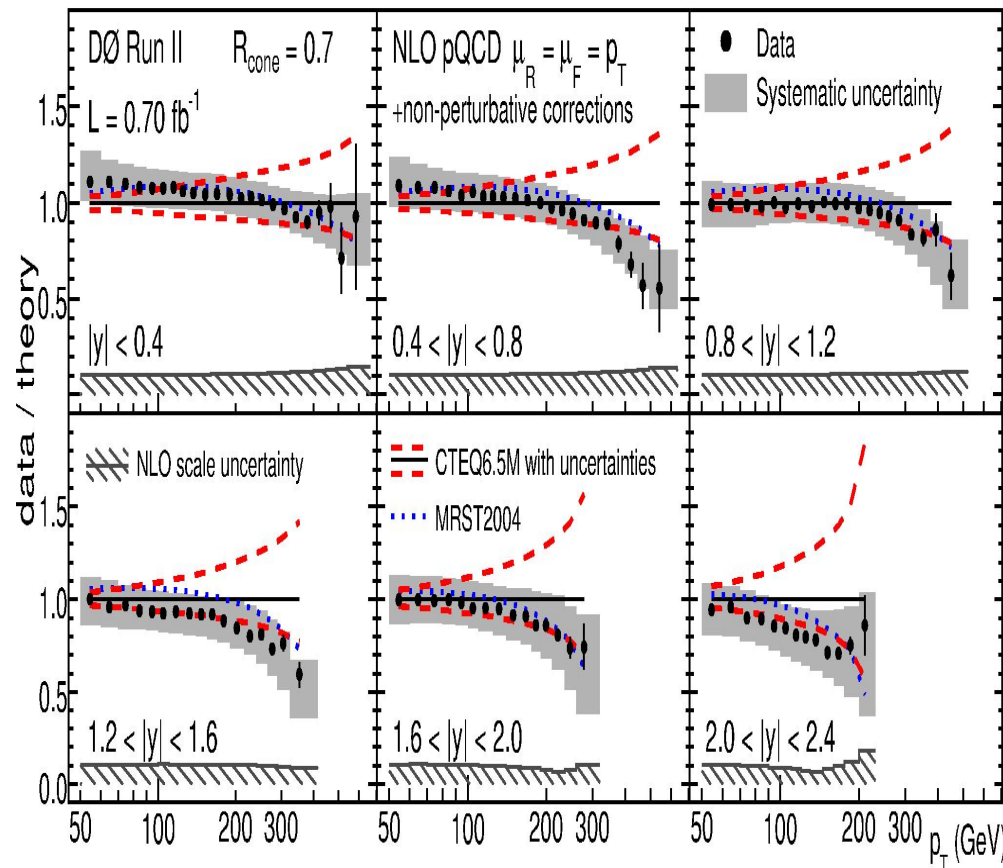
Data uncertainty smaller than that on pQCD NLO
Data prefer the lower edge of the PDF uncertainty band



DØ Inclusive Jet Results

PRL 101, 062001 (2008)

Using cone-based Midpoint Algorithm ($R=0.7$)



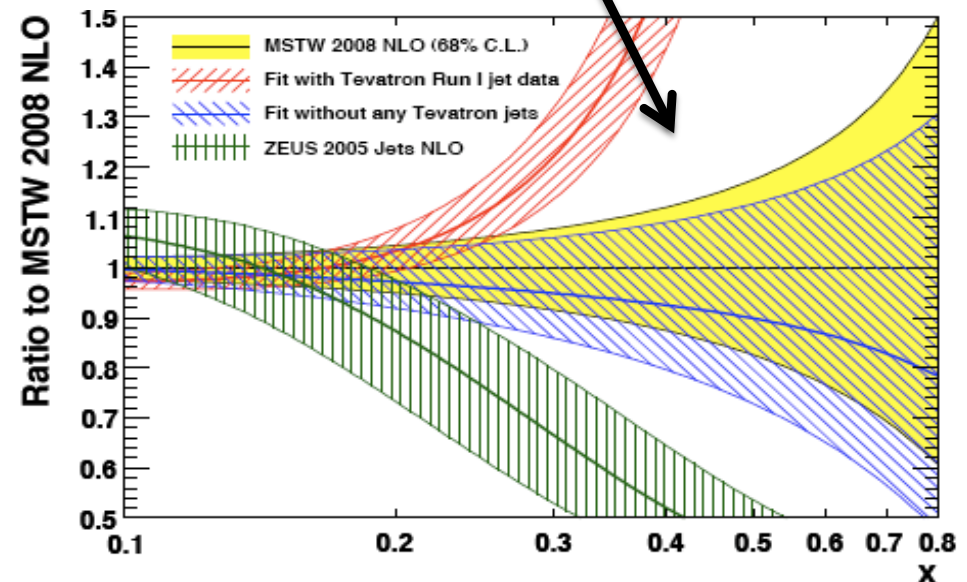
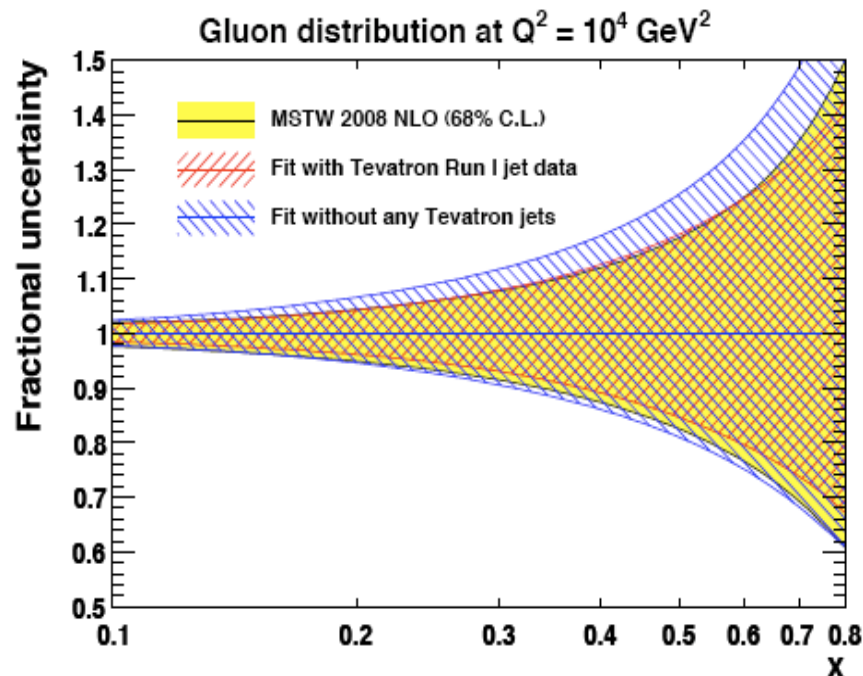
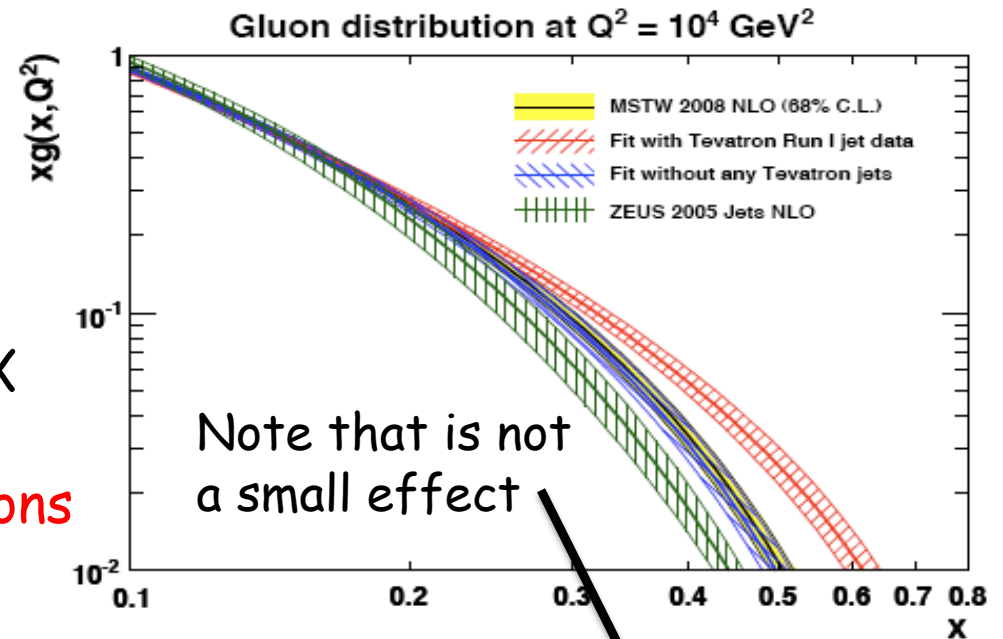
Similar conclusions using the midpoint algorithmand reduced systematic uncertainties on the absolute jet energy scale (1.2% - 2%)

New Gluon (MSTW08)

Eur. Phys. J. C 64, 653 (2009)

New MSTW analysis:

- Using CDF Kt and D0 Midpoint
- CDF and D0 data consistent
- Data dictate less gluons at high-X
- Reduced gluon PDF uncertainty
- **Reduced gluon-driven cross sections**





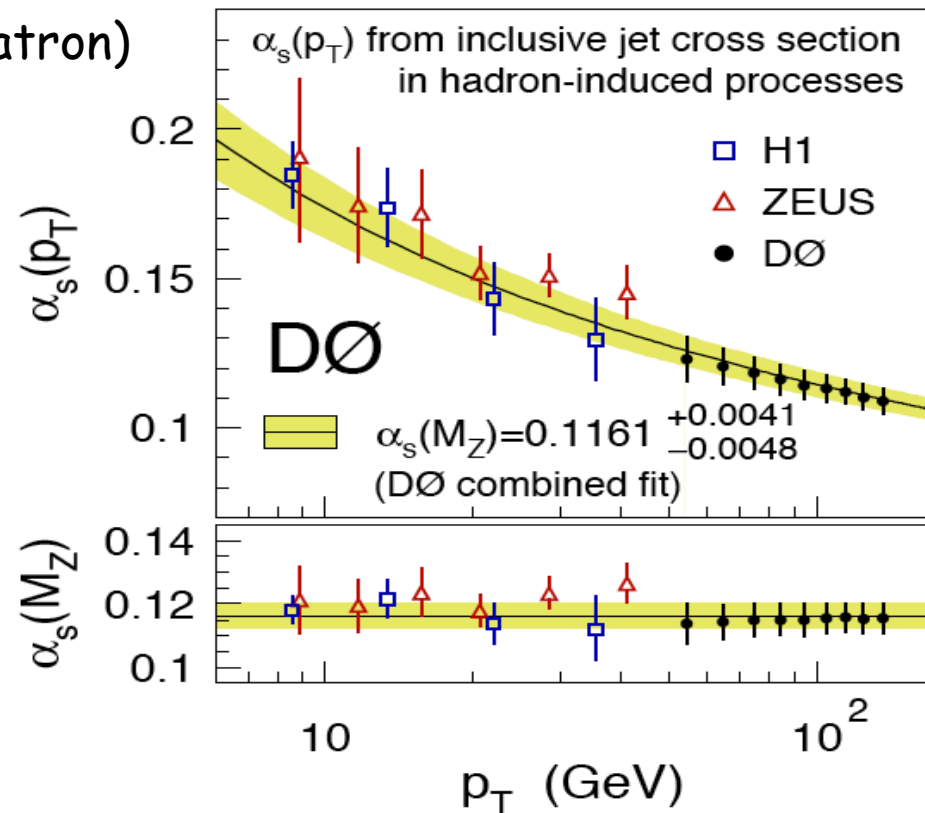
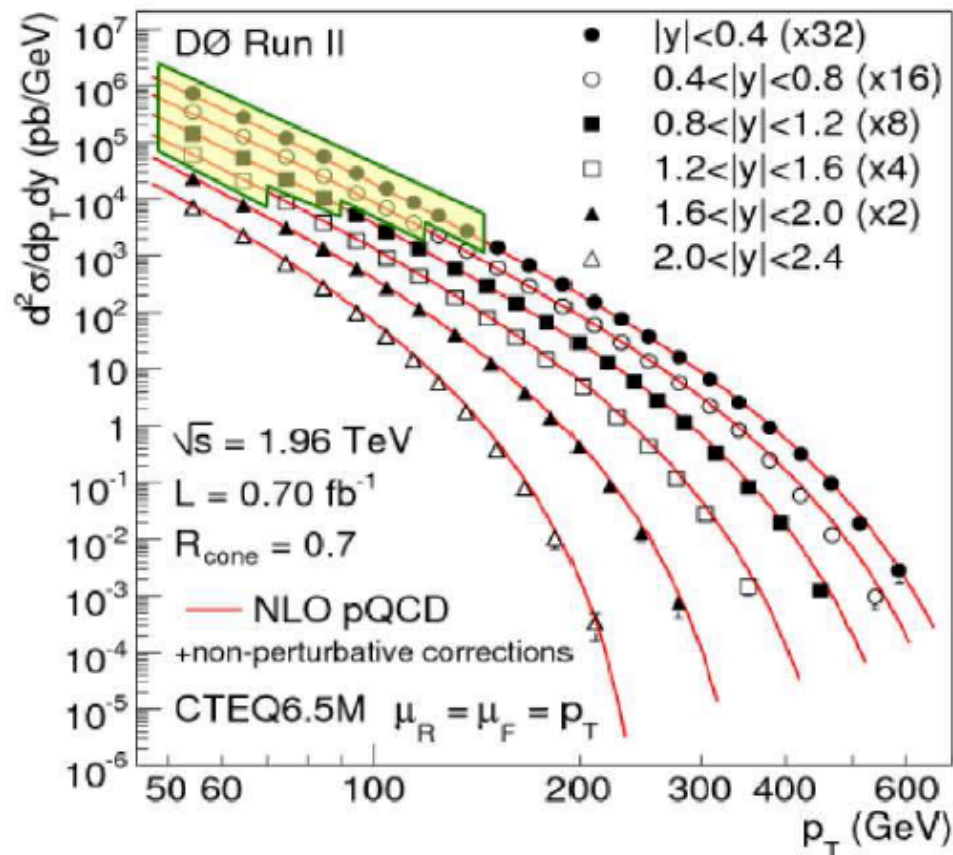
$\alpha_s(M_Z)$ determination

PRD 80,111107 (2009)

$$\sigma_{pert}(\alpha_s) = (\sum_n \alpha_s^n c_n) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s) \quad \text{NLO + (2-loops) threshold corrections}$$

Employs (NNLO) MSTW2008 PDFs
(21 different $\alpha_s(M_Z)$ values)

Based on a subset of the DØ
Inclusive Jet Cross Section data points
(avoids the PDF region dominated by Tevatron)

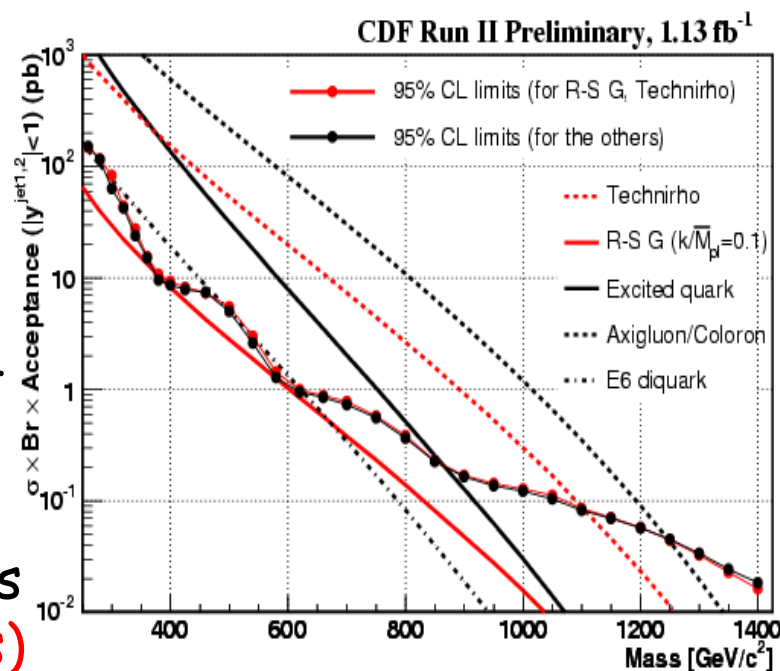
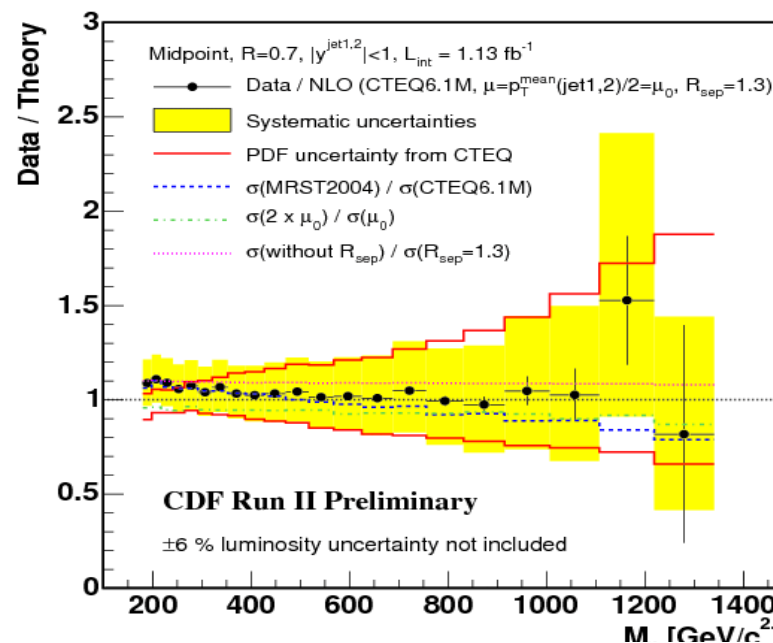
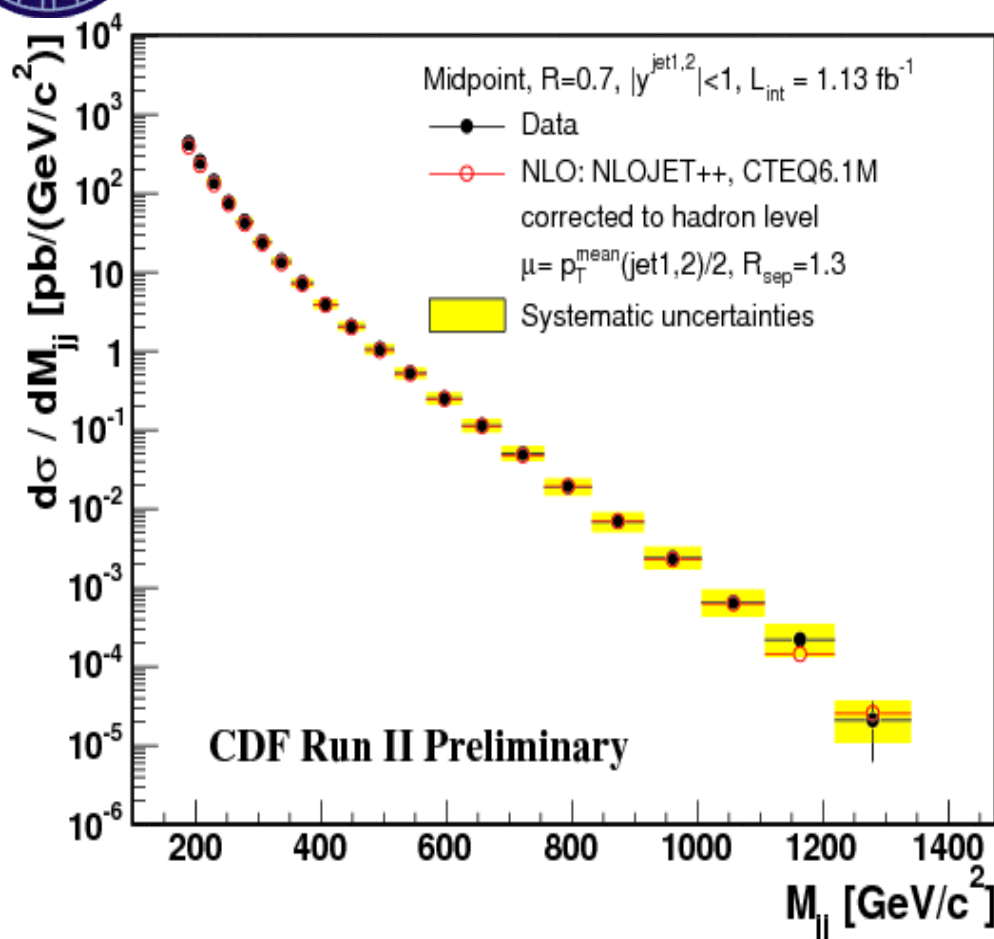


$$\alpha_s(M_Z) = 0.1161^{+0.0048}_{-0.0041}$$



Dijet Mass

PRD 79, 112002 (2009)



Dijet Mass distribution in good agreement with NLO pQCD predictions

→ Limits on new particles decaying into jets
(Now being taken over by LHC experiments)

Di-jet Production

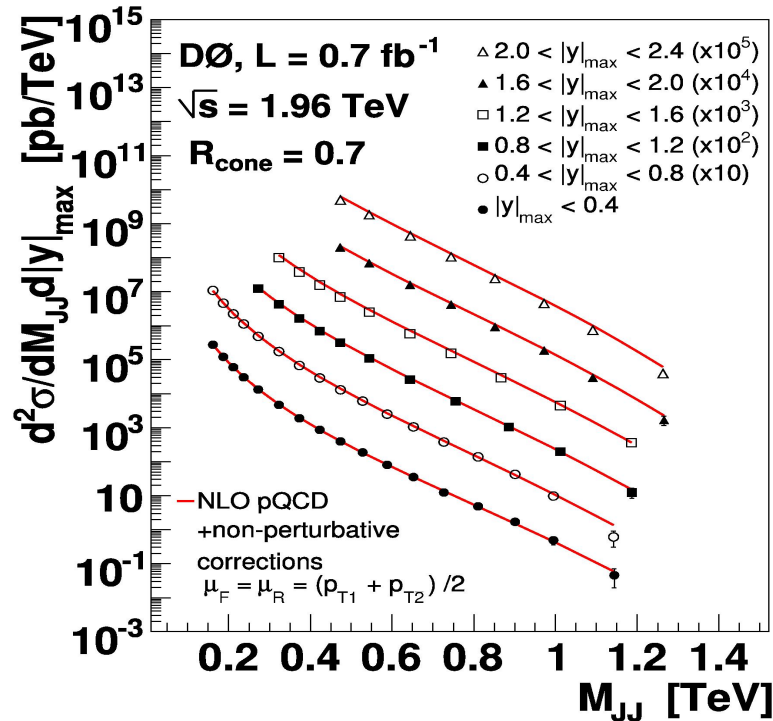


Using midpoint algorithm $R=0.7$

Double differential cross section
as a function of dijet mass and $|y_{\max}|$

In the range:

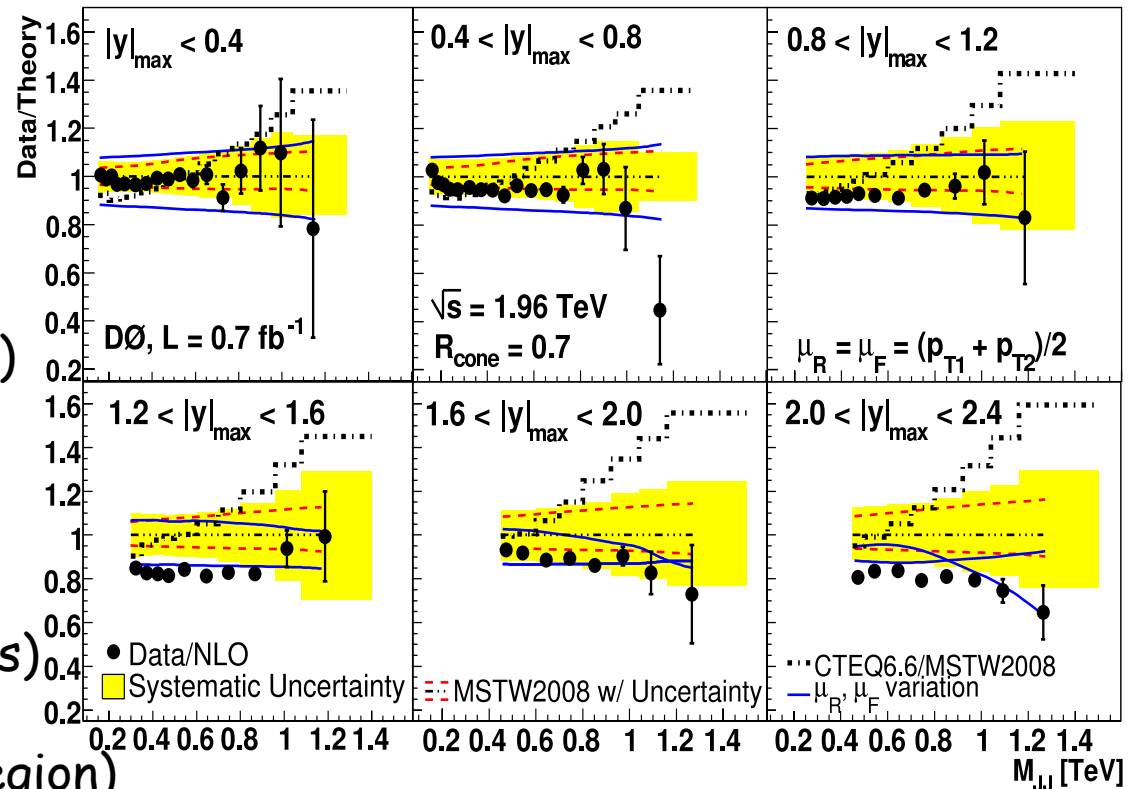
$0.15 < M_{JJ} < 1.3 \text{ TeV}$ and $|y_{\max}| < 2.4$



NLO pQCD + non-pQCD corrections
(the latter in the range -10% - 20%)

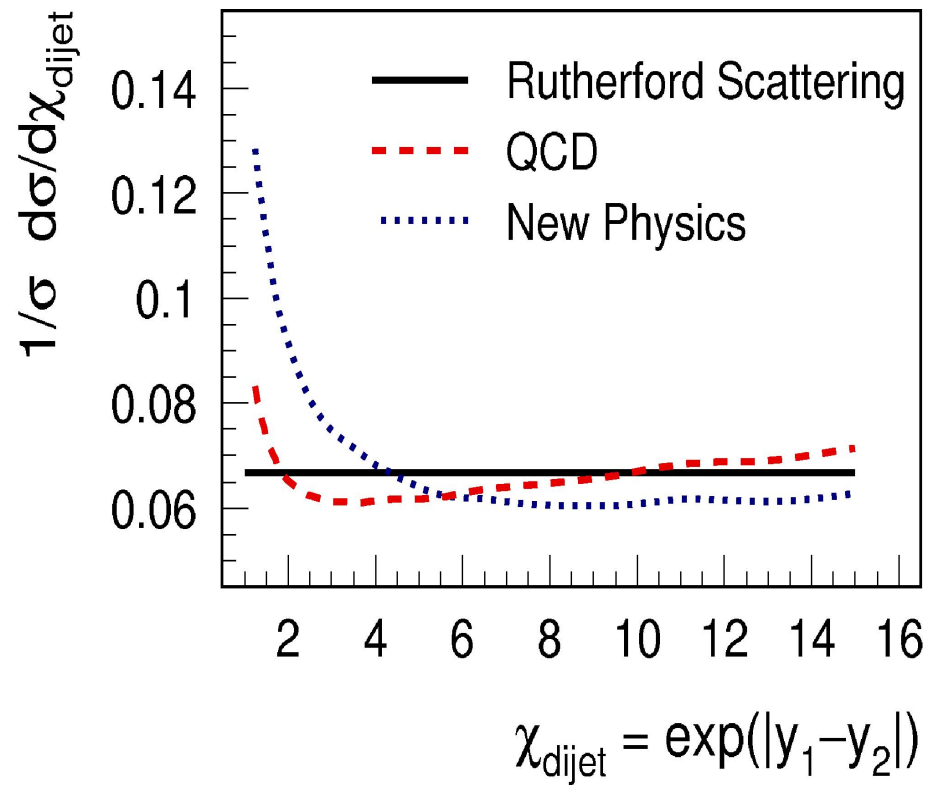
Data described by theory
when MSTW2008 PDFs are used
(note same data used to derive PDFs)

(CTEQ6.6 not so good in forward region)

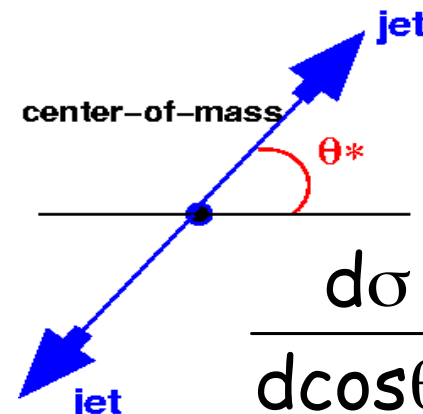


Dijet Angular Distribution

Current uncertainties on jet energy scale and gluon PDFs at high x makes difficult to claim new physics from the tail of the P_t distribution.....
.....how about QCD dynamics ?



..this also tells you gluon has spin 1..



center-of-mass

jet

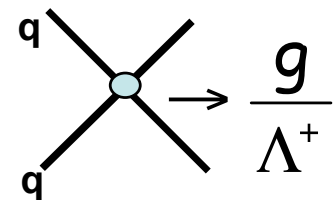
jet

$\cos \theta^* = \tanh\left(\frac{\eta_{\text{jet1}} - \eta_{\text{jet2}}}{2}\right)$

$\frac{d\sigma}{d\cos\theta^*} \approx \frac{1}{(1 - \cos\theta^*)^2}$

(dominant t-channel gluon exchange)

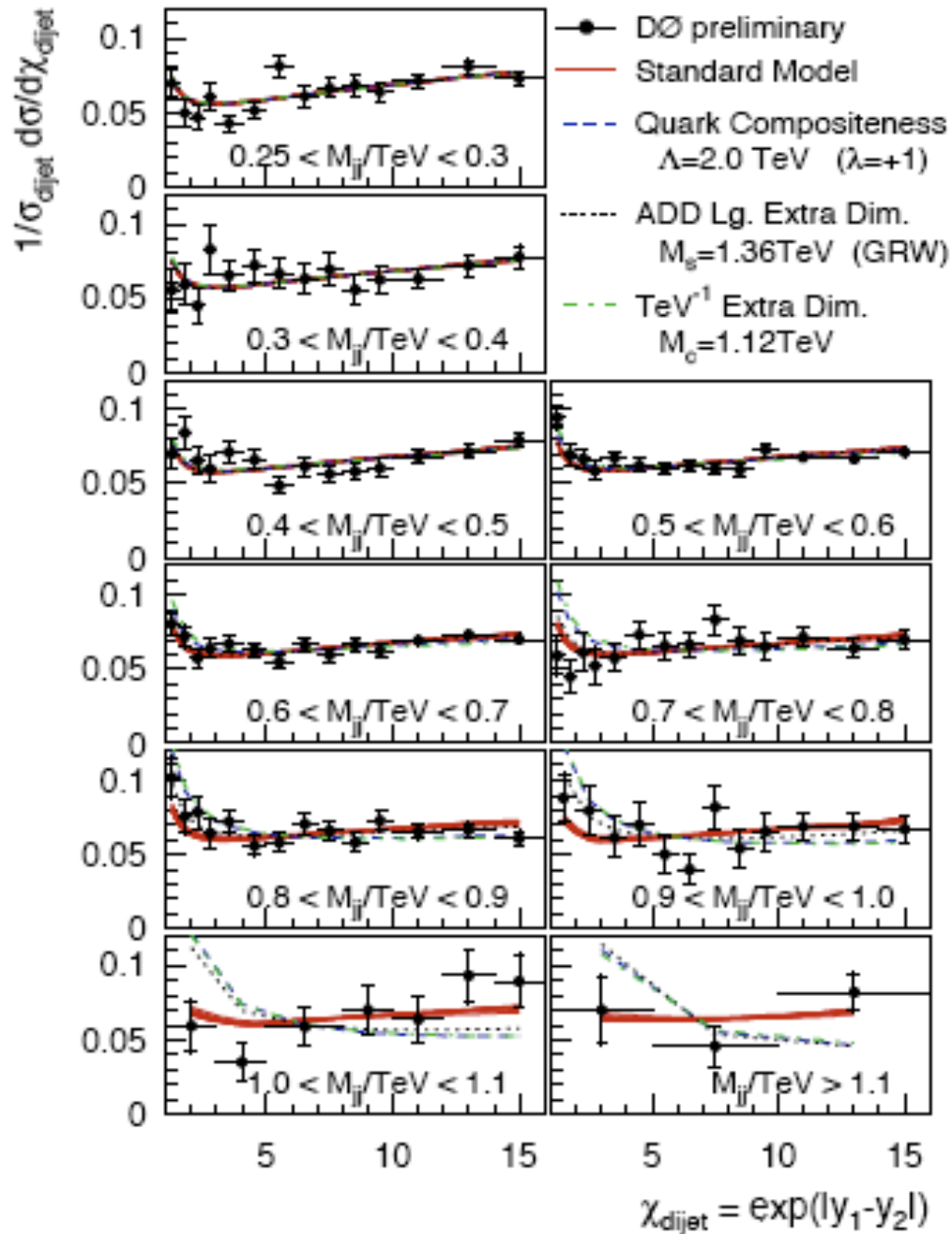
The presence of quark compositeness at scale Λ would add terms like



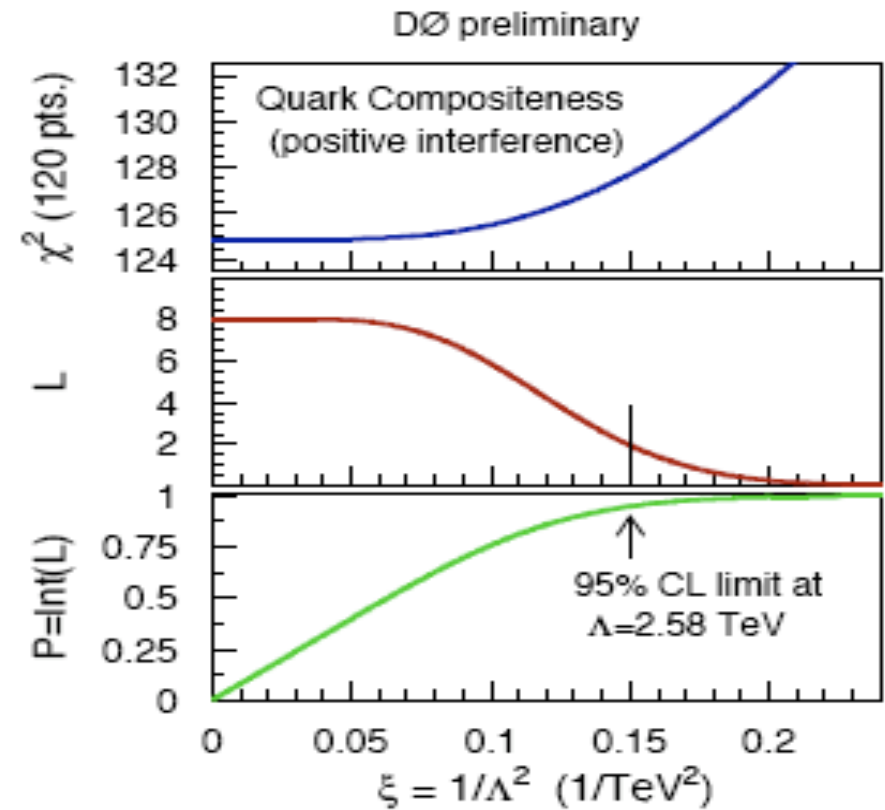
$\frac{d\sigma^{\text{new}}}{d\cos\theta^*} \approx \frac{1}{(1 + \cos\theta^*)^2}$

We define then

$$\chi = \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$



$$\sigma_{\text{NP}} = \text{SM} + \frac{\lambda}{\Lambda^2} \text{Interf.} + \frac{\lambda^2}{\Lambda^4} \text{NP}$$



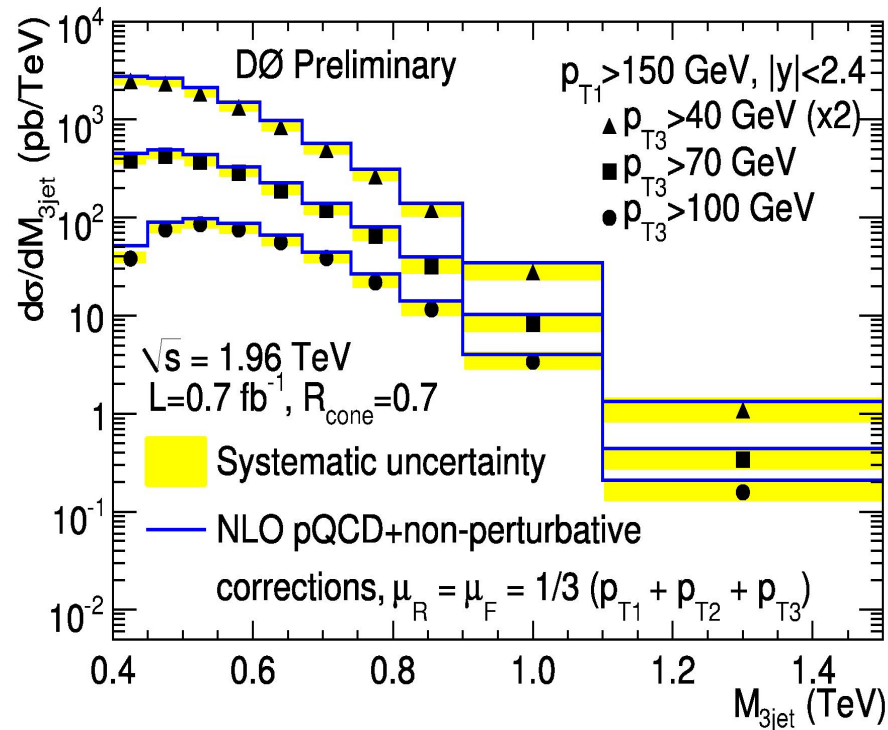
This analysis excludes compositeness with scale less than 2.58 TeV@ 95%CL

Good agreement with QCD predictions



Multi-jet Production

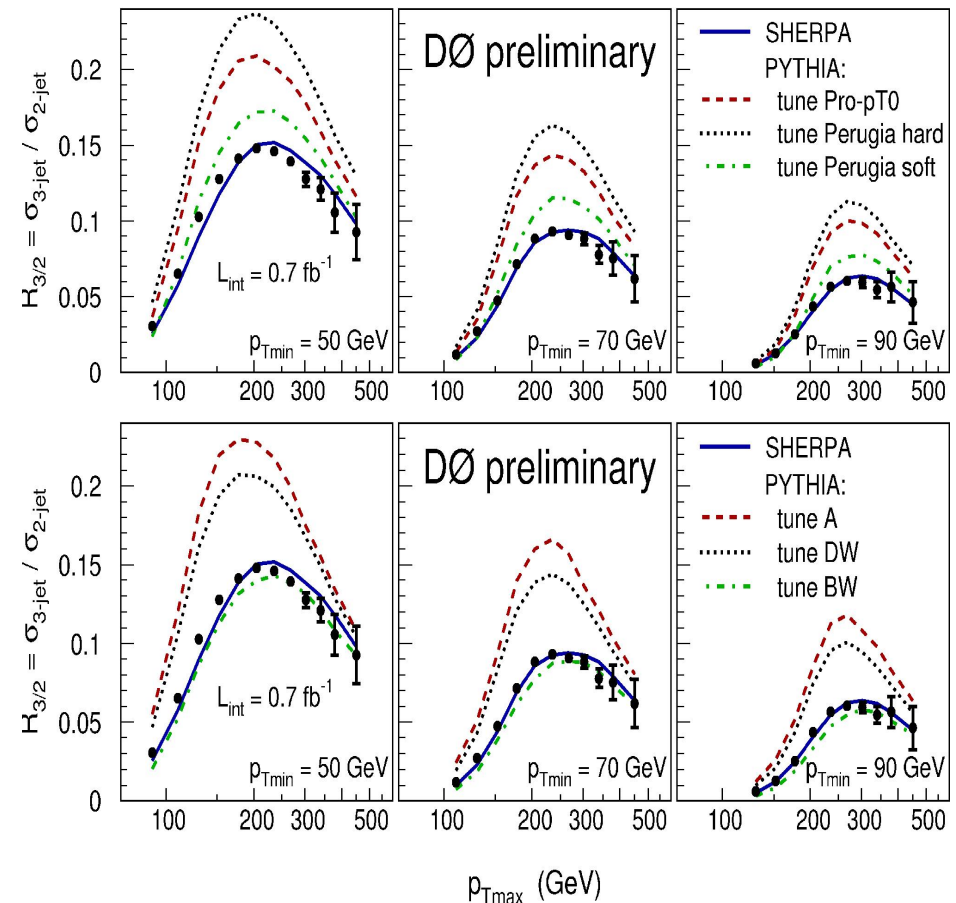
Three-jet mass cross section
for well separated jets ($R_{ij} > 1.4$)
in different regions of p_{T3}



Data reasonably well described by
NLO pQCD + non-pQCD corrections
(using MSTW2008 PDFs)

Ratio R (3jets/2jets) vs p_T leading jet

$$p_{T\text{max}} > p_{T\text{min}} + 30 \text{ GeV}$$



Compared to different LO ME + PS predictions
→ Sherpa provides the best description...
followed by PYTHIA (tune BW)...



Substructure of high p_T jets

6.0 fb⁻¹

Very relevant in searches for new physics using boosted objects

Midpoint $R=0.7$

$p_T > 400$ GeV

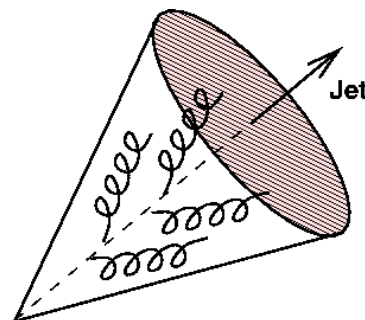
$0.1 < |\eta| < 0.7$

To reject top:

$M^{\text{jet}}(2^{\text{nd}}) < 100$ GeV

$\text{MET}/\sqrt{E_T} < 4$

$p_T(2^{\text{nd}}) > 100$ GeV



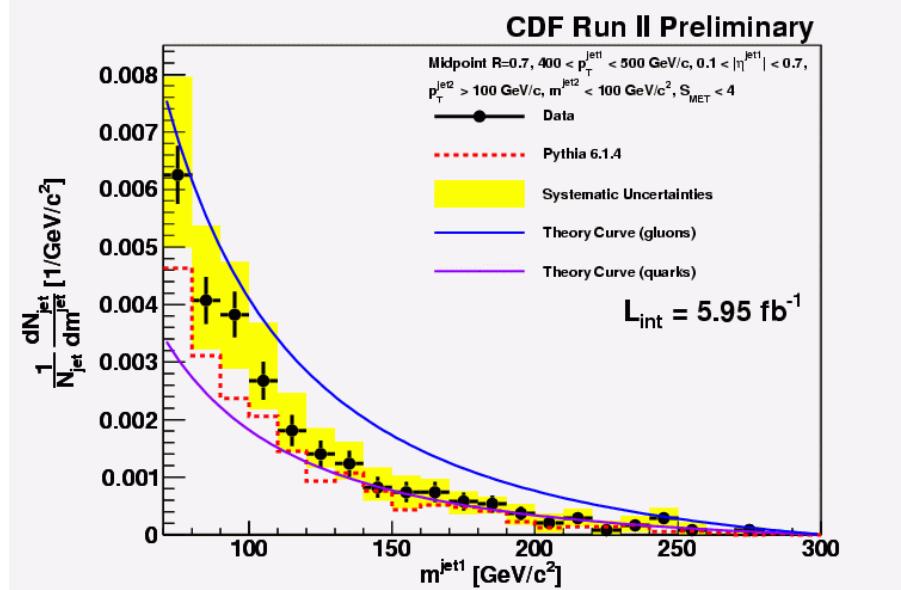
Angularity:

tower energies

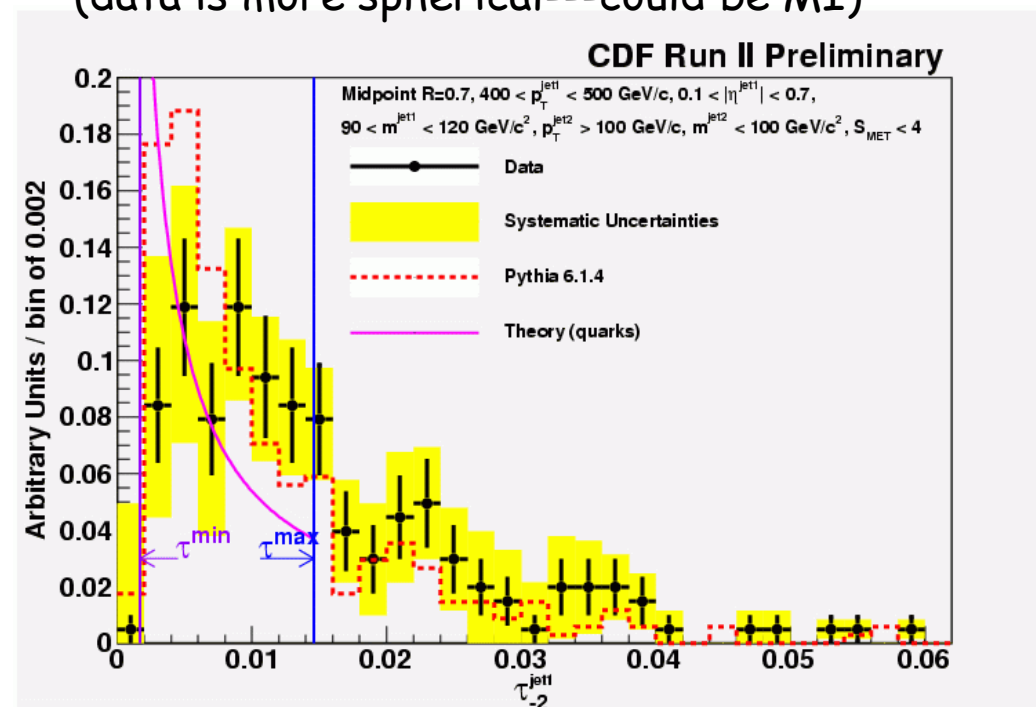
$$\tau_a(R, p_T) = \frac{1}{m_J} \sum_i \omega_i \sin^a \theta_i [1 - \cos \theta_i]^{1-a}$$

Study the energy distribution inside jet
(can distinguish QCD q/g from boosted heavy particle decays)

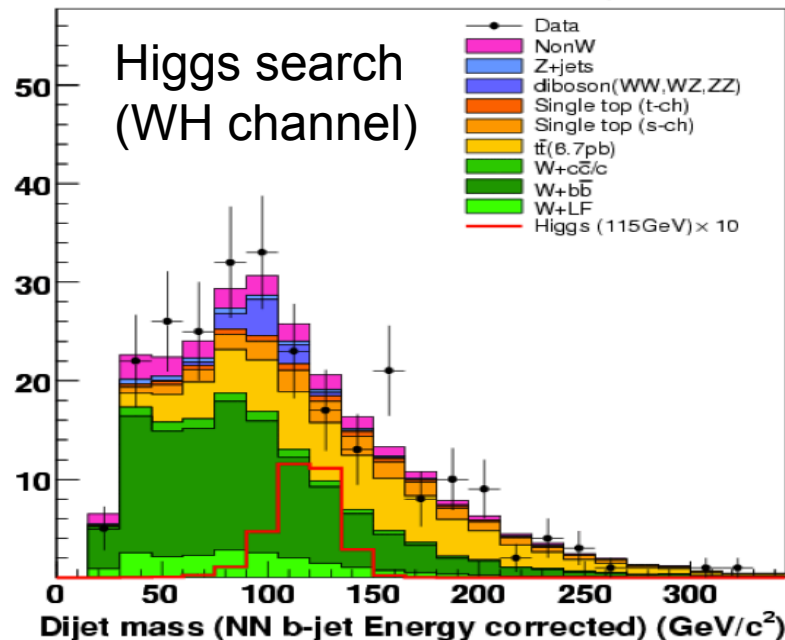
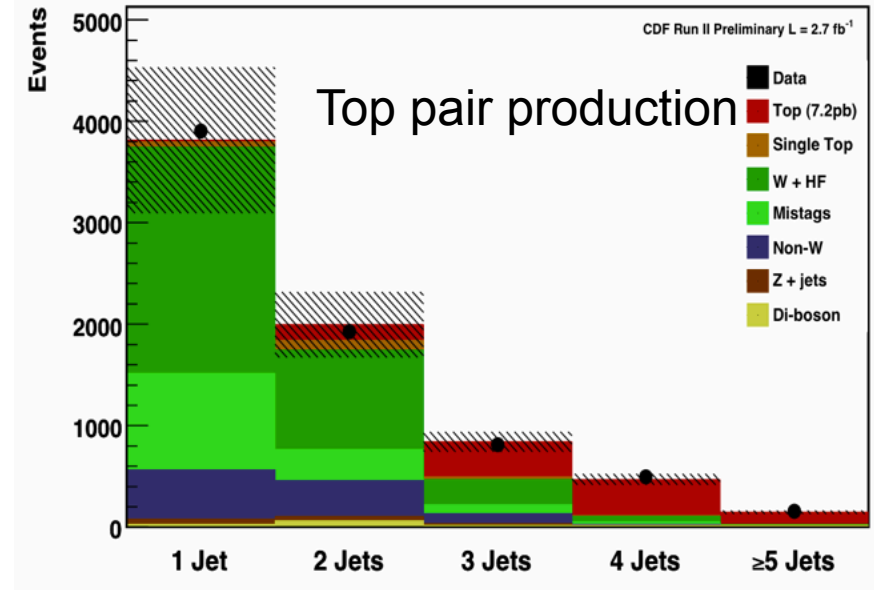
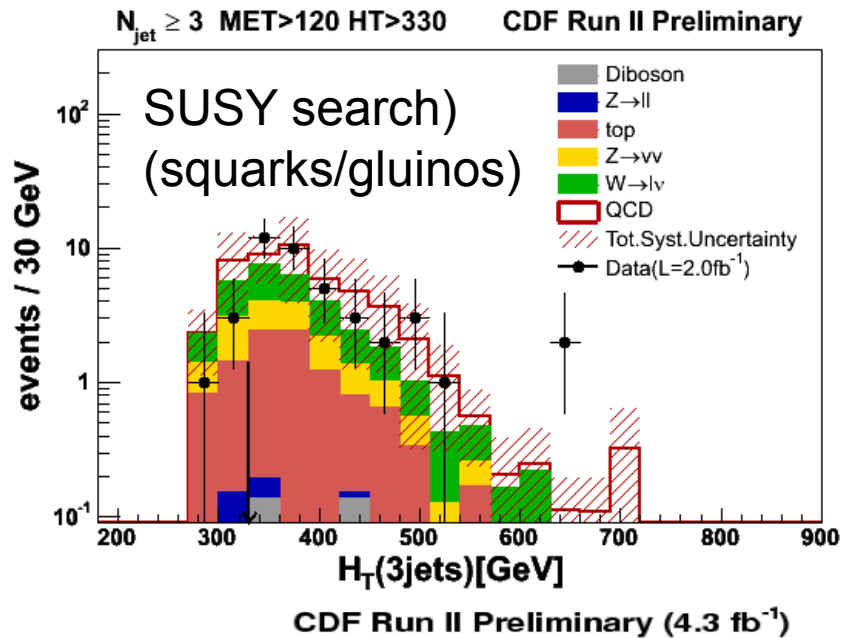
Invariant mass of leading jet:
PYTHIA softer than the data
(80% quark initiated jets expected)



→PYTHIA peaks at low values
(data is more spherical---could be MI)



W/Z+jets (Motivation)



• Boson + Jet(s) Processes constitute in many cases irreducible backgrounds in searches for new physics

30% - 40% uncertainty in some of the processes (boson + HF)

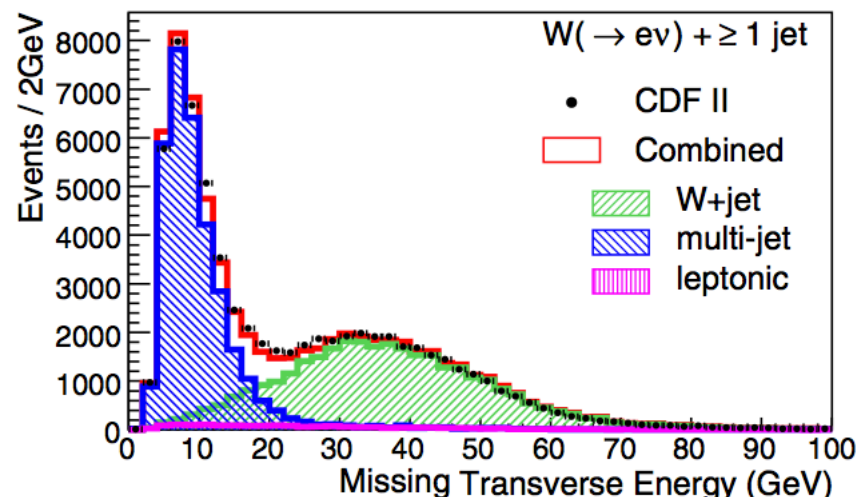
→ Call for dedicate measurements on boson+jets



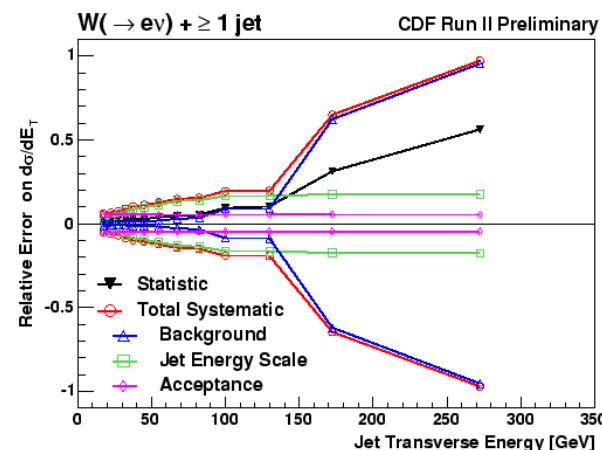
$W(-\rightarrow ev) + \text{jet}(s)$

Phys. Rev. D 77, 011108(R) (2008)

- CDF standard electron ID
 - $E_T^e > 20 \text{ GeV}$
 - $|\eta^e| < 1.1$
 - $\text{MET} > 30 \text{ GeV}, M_T^W > 20 \text{ GeV}$
- At least one jet JetClu ($R=0.4$)
 - $E_T^{\text{jet}} > 20 \text{ GeV}/c, |\eta^{\text{jet}}| < 2.0$
 - $\Delta R(e\text{-jet}) > 0.52$
- Measurement corrected for detector and defined in the given limited kinematic region (no extrapolation made)
- Comparison with ME+PS implementations and different matching procedures
 - MADGRAPH v4 + PYTHIA 6.3 (CKKW)
 - ALPGENv2 + HERWIG 6.5 (MLM)
- Comparison with NLO pQCD (MCFM) CTEQ6.1M and $\mu^2 = M_W^2 + (P_T^W)^2$

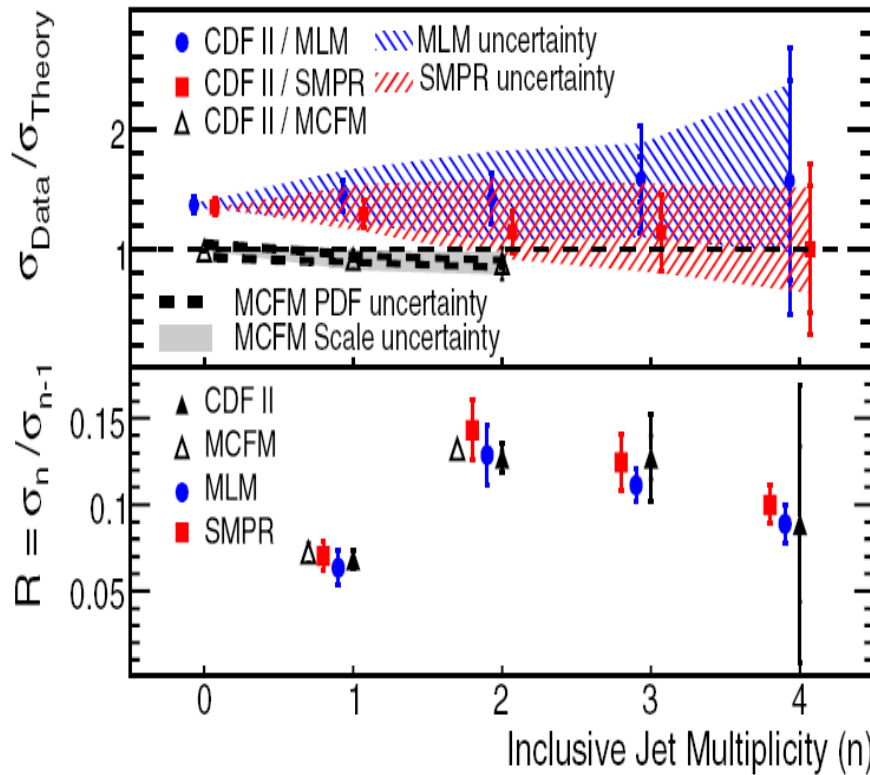
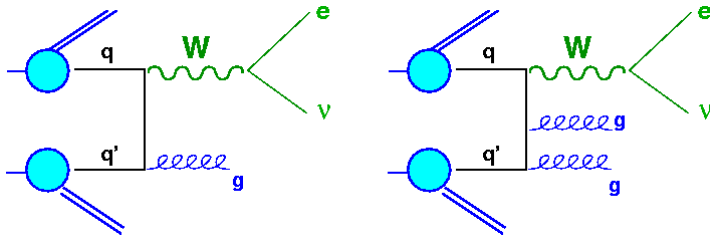


Background taken from fit to MET and lepton P_T distributions



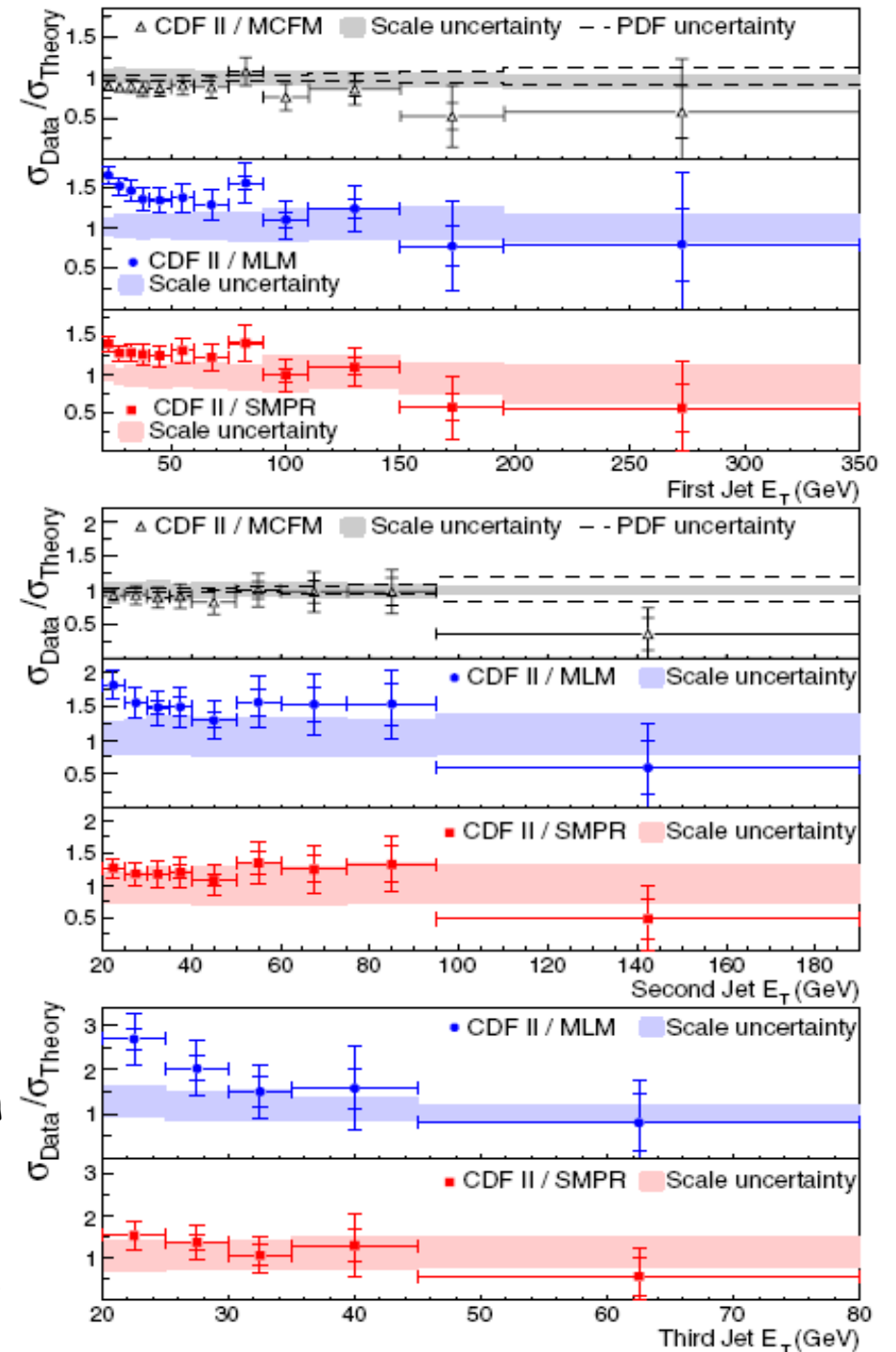
(Background dominates de measurement at large E_T^{JET} due mainly to top backgr.)

W+jet(s)



Good agreement with pQCD NLO calculation

ME+ PS needs UE contributions at low P_T and suffers scale uncertainties at large N_{jet} but describes the σ_N/σ_{N-1} ratios

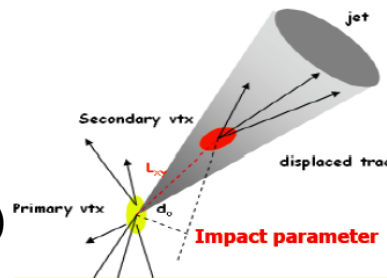
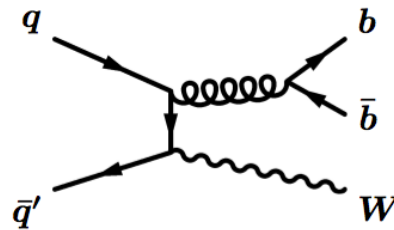




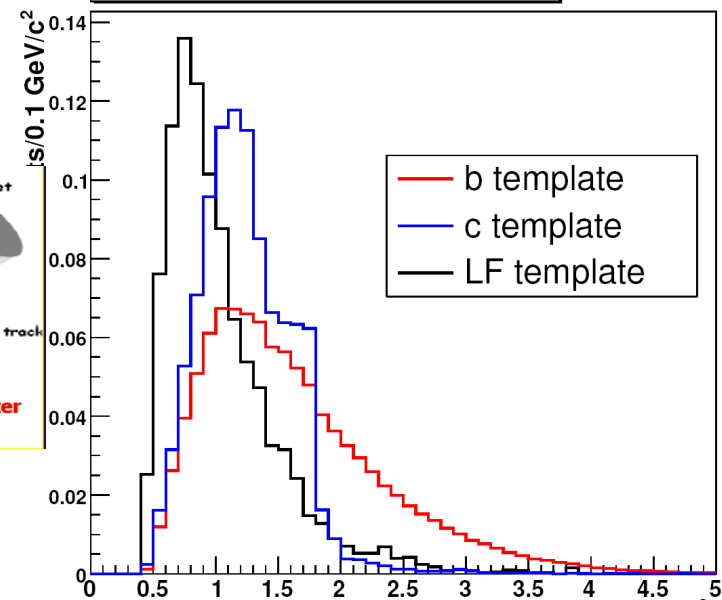
W + b-jet(s)

PRL 104, 131801 (2010)

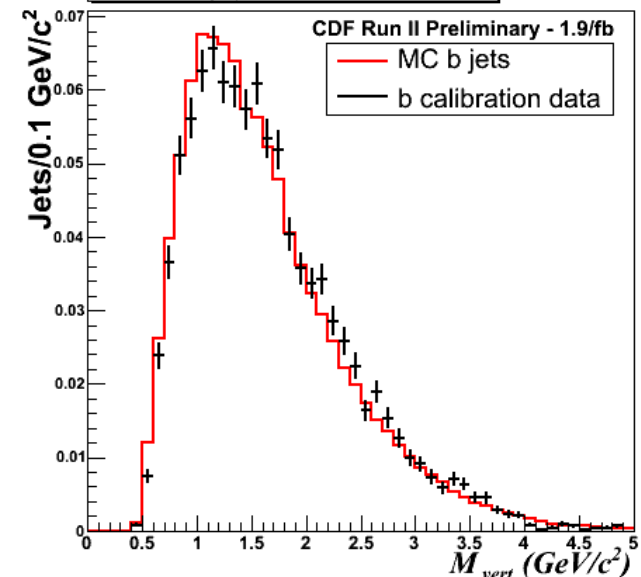
- Both electron and (muon) channels
 - $P_T > 20 \text{ GeV}/c$
 - $|\eta| < 1.1$
 - $\text{MET} > 25 \text{ GeV}$
- Exactly one or two jets JetClu ($R=0.4$)
 - $E_T^{\text{jet}} > 20 \text{ GeV}/c$
 - $|\eta^{\text{jet}}| < 2.0$
 - One b-tagged jet (SVTX ultra-tight)
- B-quark composition extracted from fit to secondary vertex mass
 - Templates for light, charm and bottom taken from MC
 - Validated in control samples in data
- Physics Processes that contribute:
 - W+b/c production (taken from ALPGEN)
 - Top and dibosons (taken from PYTHIA)
 - Single top production (taken from MADEVENT)
 - QCD multijets (from DATA)
- Comparison with theory in the restricted phase space (no extrapolation is made)



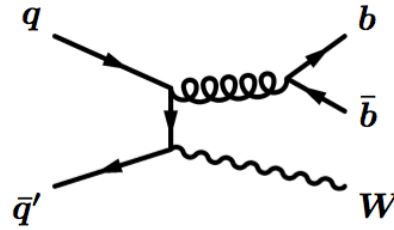
Vertex Mass Templates



b M_{vert} Calibration



W+b-jet(s)



Fraction of b-jets : 0.71 ± 0.05

In 1.9 fb^{-1}

TOTAL : $670 \pm 44 \text{ (stat.)}$ b-tagged jets

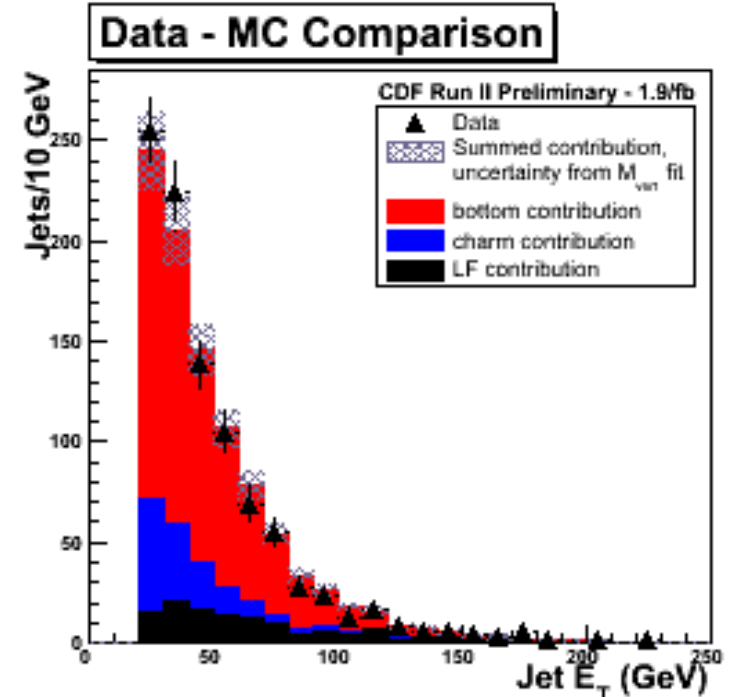
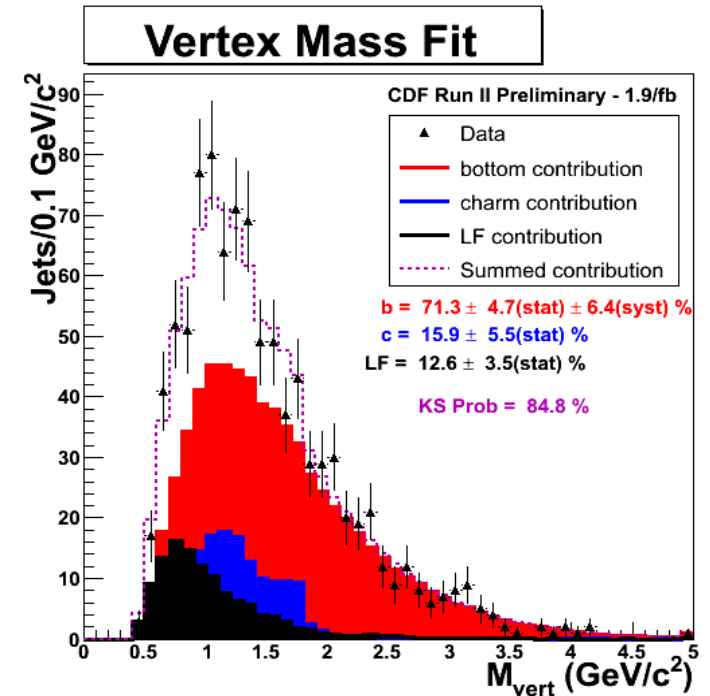
BACKG.: $177 \pm 22 \text{ (stat.)}$ “

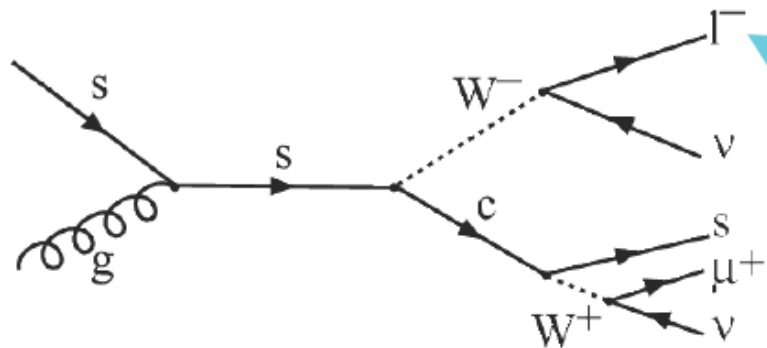
18% uncertainty on the measurement
vertex modeling (8%)
b-tag effi. (6%), lumi. (6%)

$$\sigma_{\text{bjets}} (W + b \text{ jets}) \times \text{BR}(W \rightarrow l\nu) = 2.74 \pm 0.27 \pm 0.42 \text{ pb}$$

$$\text{ALPGENv2 + PYTHIA 6.3} \\ (Q^2 = M_W^2 + P_{T,W}^2) = 0.78 \text{ pb}$$

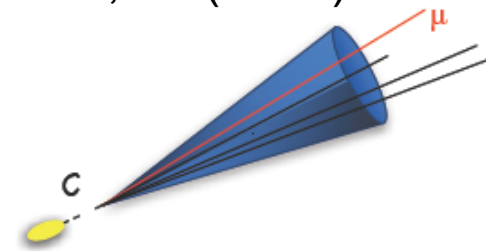
$$\text{NLO pQCD} = 1.22 \pm 0.14 \text{ pb}$$





W+c

CDF: PRL 100, 091803 (2008)
D0: PLB 666, 23 (2008)



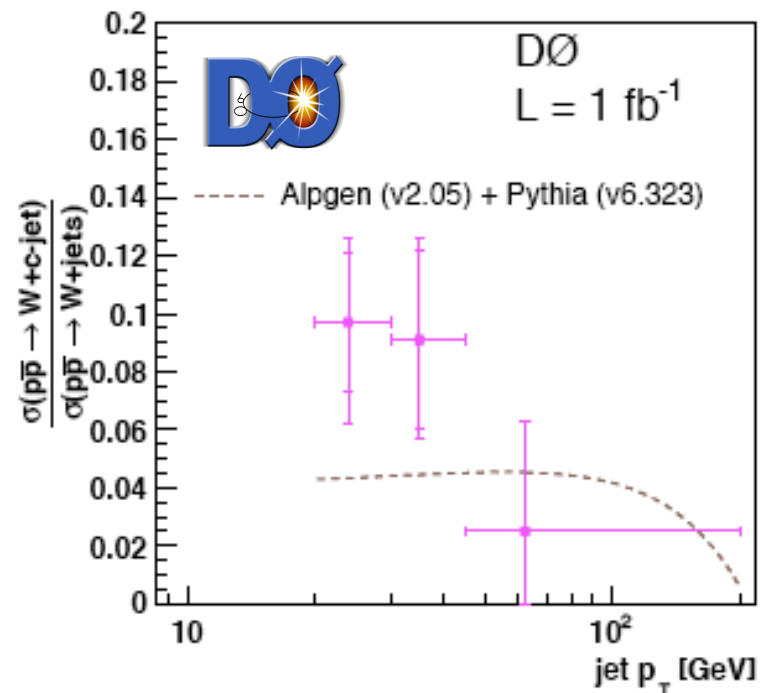
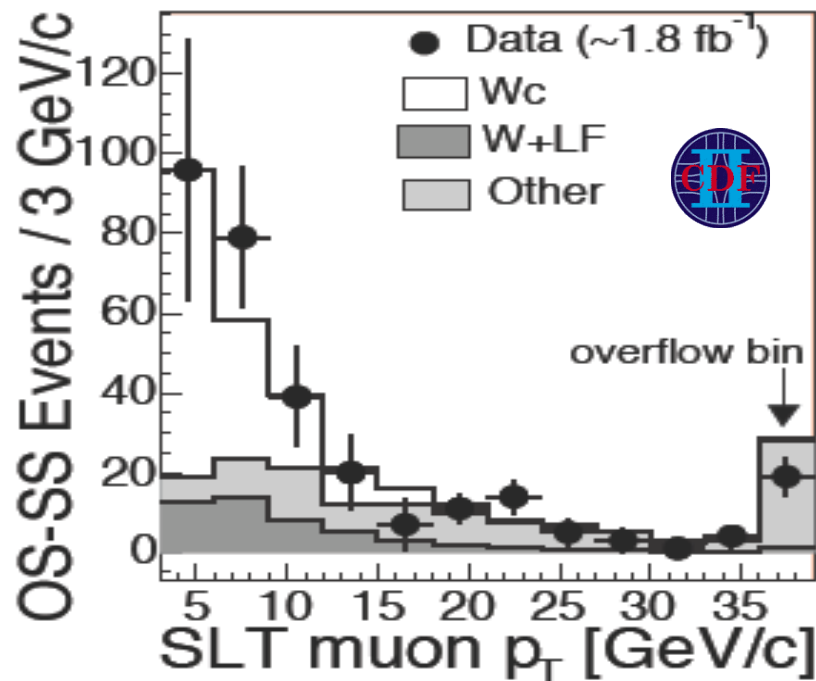
Use charge correlation between leptons
To obtain the signal W+c from OS-SS

Events with a high-pt lepton, MET/MT
and at least a jet with a soft pt lepton

$$\sigma_{Wc} \times Br(W \rightarrow l\nu) = 9.8(stat.) \pm 2.8_{-1.6}^{+1.4}(syst.) pb$$

$$NLO: 11.0_{-3.0}^{+1.4} pb (p_{Tc} > 20 GeV/c, |\eta_c| < 1.5)$$

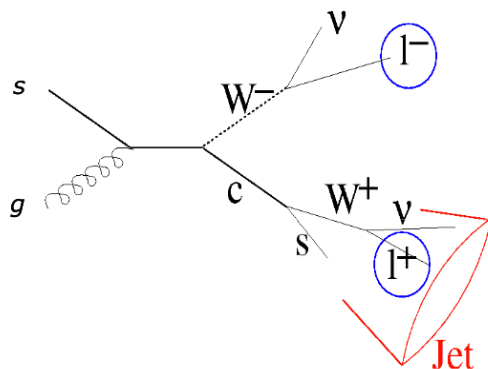
D0 uses both e and μ soft leptons
For jets with $P_t > 20 GeV$, $|\eta| < 2.5$
W+c/W+jets agrees with LO pQCD





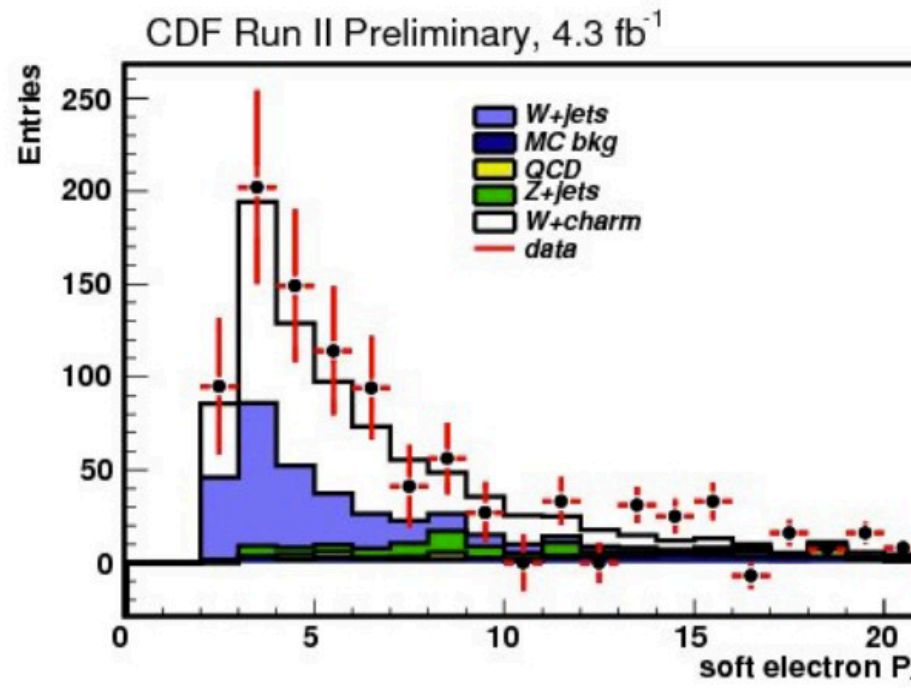
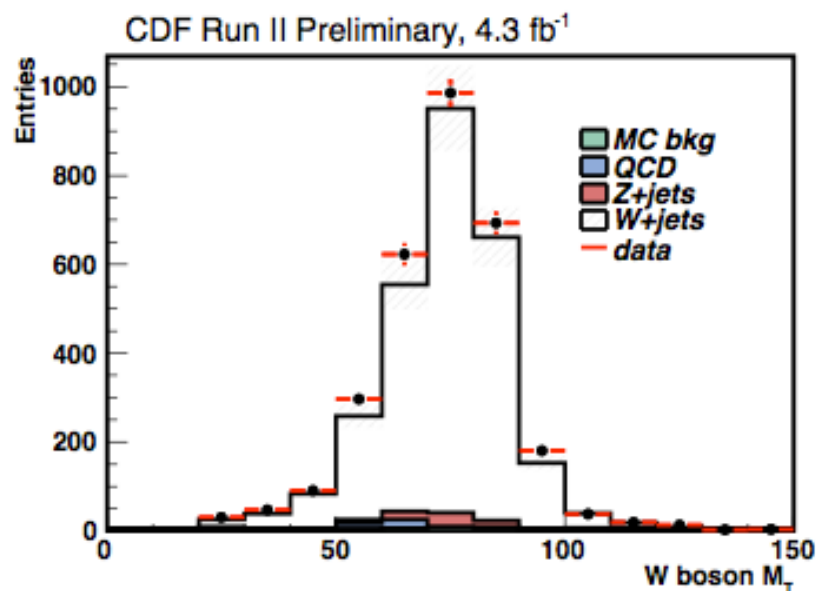
W+c

Electron channel



4.3 fb⁻¹

$$\sigma_{W+c} \times Br(W \rightarrow l\nu) = \frac{N_{measured}^{OS-SS} - N_{bkg}^{OS-SS}}{L \times A \times \epsilon}$$



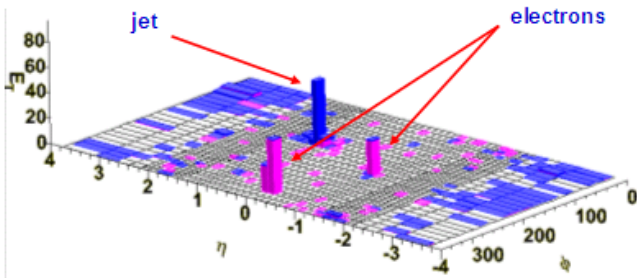
Charm : $p_T > 20\text{GeV}, |\eta| < 1.5$

$\sigma_{Wc} \times Br(W \rightarrow l\nu) = 21.1 \pm 7.1(\text{stat.}) \pm 4.6(\text{syst.}) \text{pb}$

ALPGEN : $16.5 \pm 4.7 \text{pb}$

NLO(MCFM) : $11.0^{+1.4}_{-3.0} \text{pb}$

Reasonable agreement with NLO pQCD
(within large experimental uncertainties)



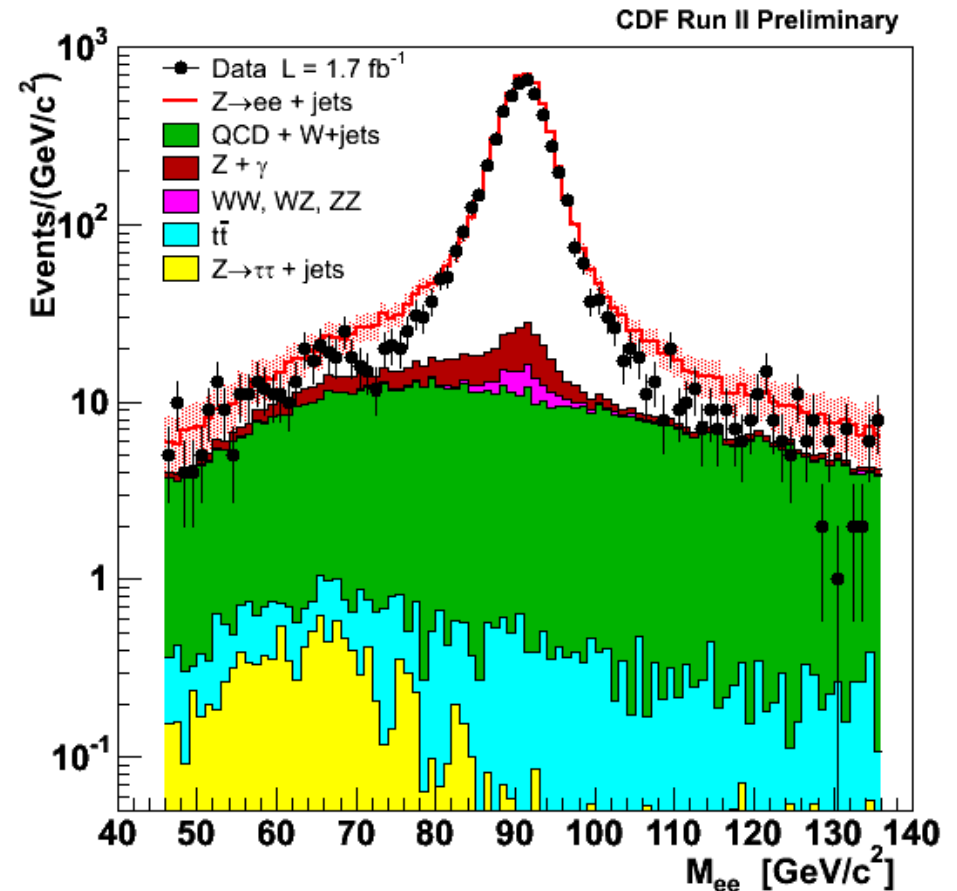
$Z/\gamma^*(-\rightarrow ee) + \text{jet}(s)$

Phys. Rev. Lett. 100, 102001 (2008)



Updated results based on 2.5 fb^{-1}

- CDF standard electron ID
 - At least one central electron
 - $E_T^{e1} > 25 \text{ GeV}$
 - $|\eta^{e1}| < 1, |\eta^{e2}| < 1$ or $1.2 < |\eta^{e2}| < 2.8$
 - $66 < M_{ee} < 116 \text{ GeV}/c^2$
 - No isolation requirements (avoids bias at very high P_T^{jet})
- At least one jet MidPoint ($R=0.7$)
 - Electrons removed before clustering
 - $P_T^{\text{jet}} > 30 \text{ GeV}/c$
 - $|\eta^{\text{jet}}| < 2.1$
 - $\Delta R(e\text{-jet}) > 0.7$
- Measurement corrected for detector effects back to the hadron level and defined in the given limited kinematic region (no extrapolation made)

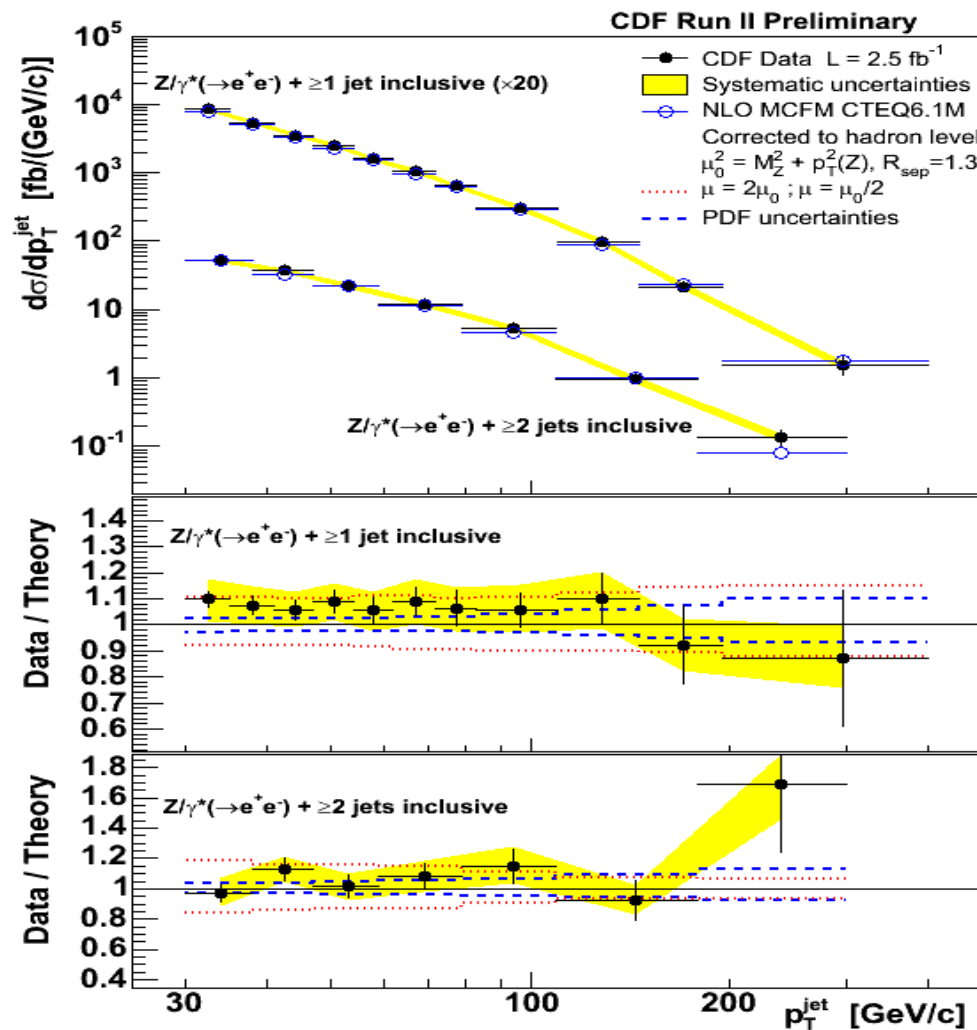
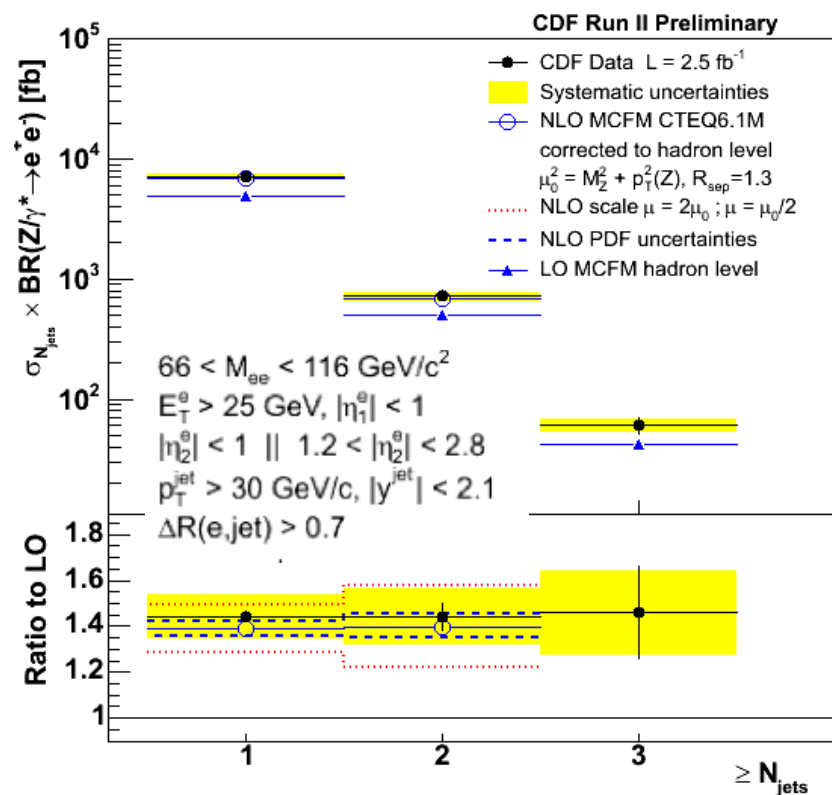
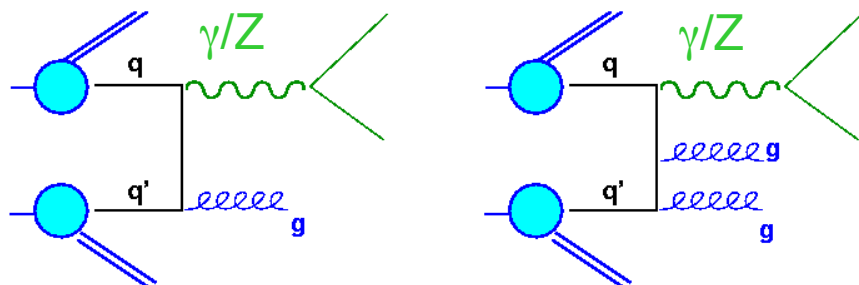
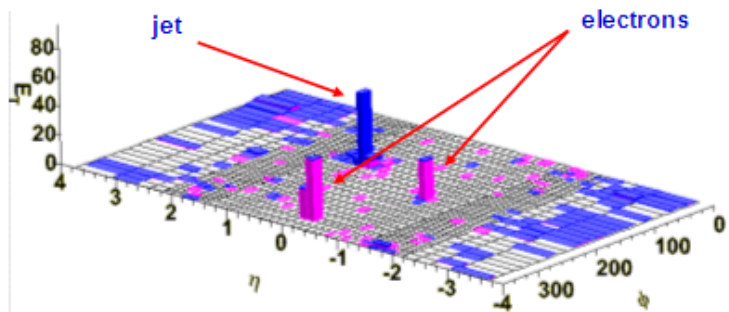


Background at the level of 12% - 17% (dominated by QCD and W+jets)

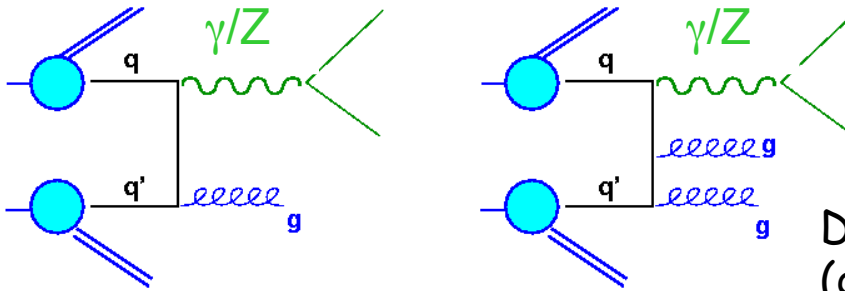


$Z/\gamma^*(-\rightarrow ee) + \text{jet}(s)$

Inclusive jet differential cross sections



Good agreement with NLO pQCD predictions including non-pQCD corrections



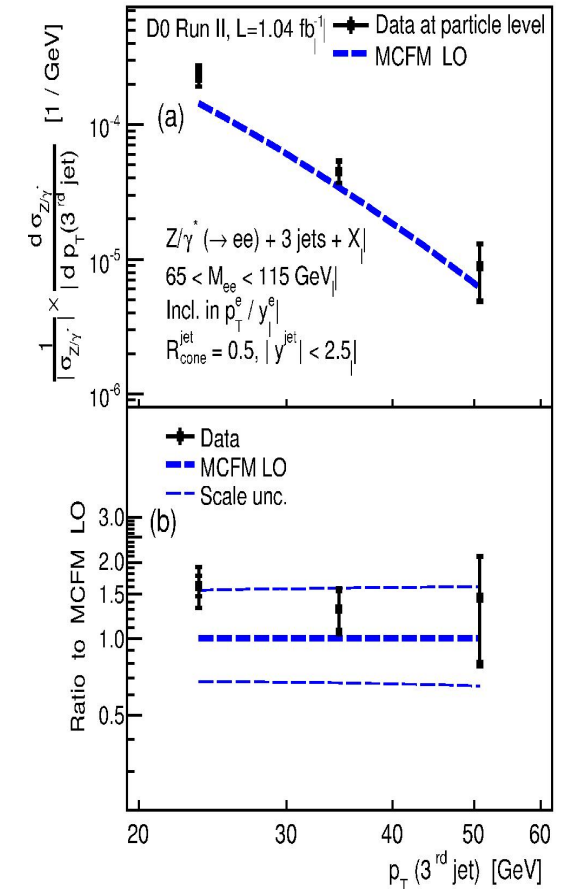
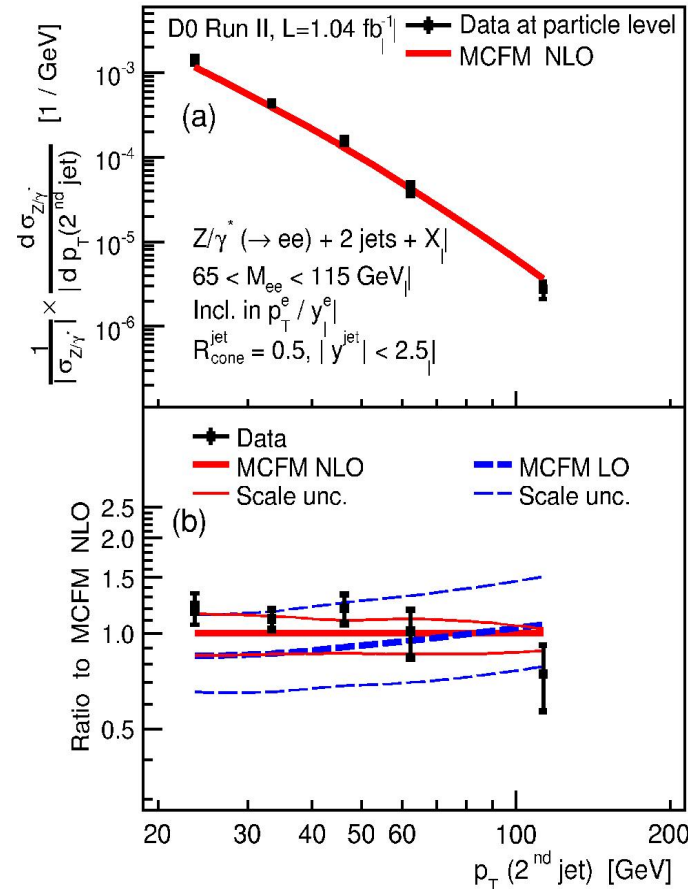
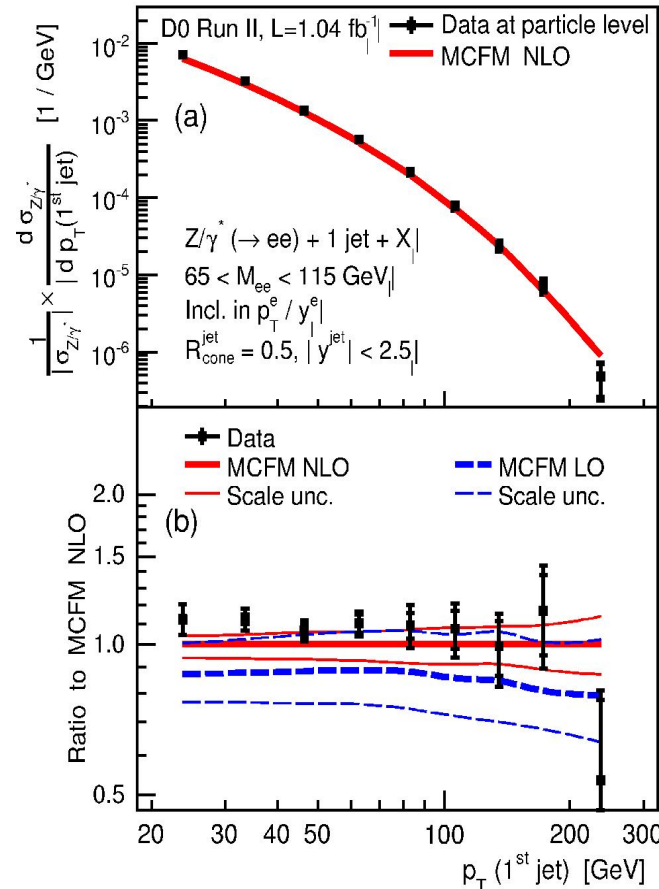
$Z/\gamma^*(-\rightarrow ee) + \text{jet}(s)$

PLB 678, 45 (2009)

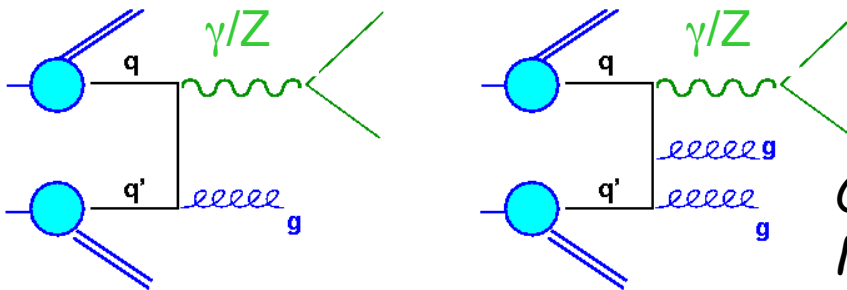


1.0 fb⁻¹

Differential cross sections of the n^{th} jet p_T
(divided by DY cross section)



Similar conclusions as in the CDF case: NLO pQCD describes the data
 For the 3-jet case (only LO pQCD available) underestimates the data by ~ 1.5

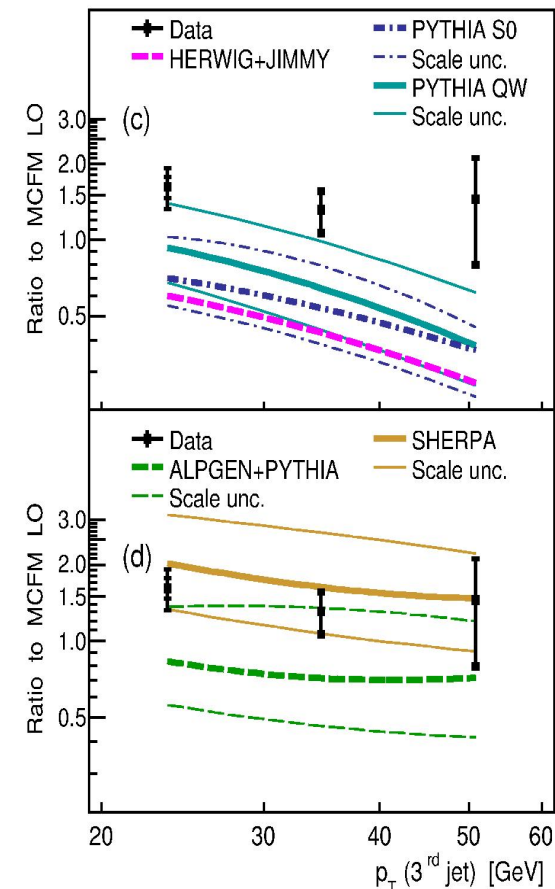
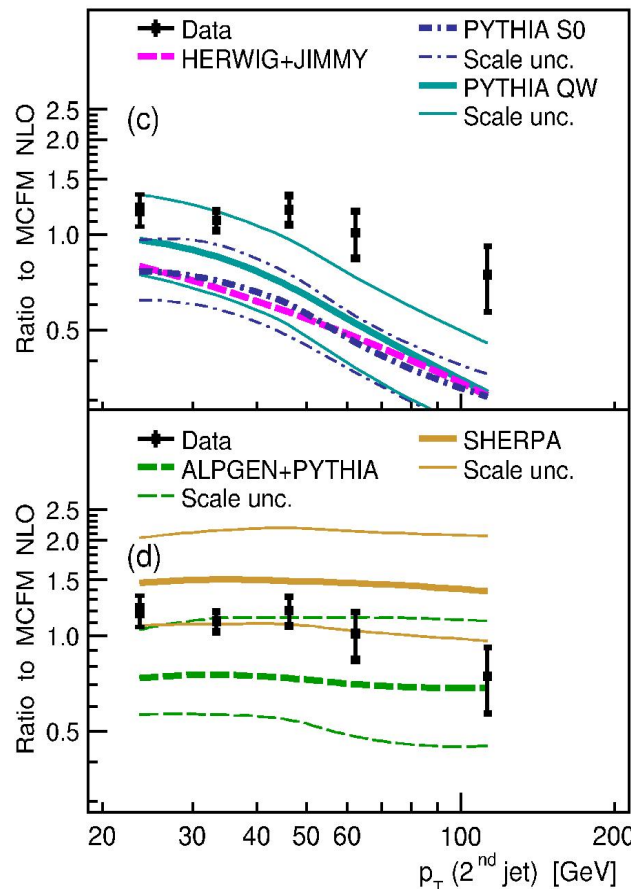
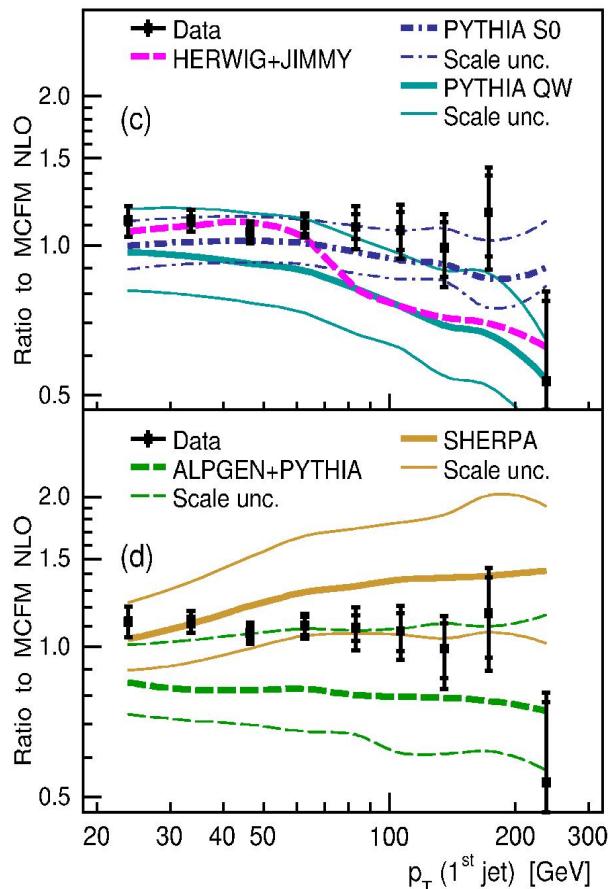


$Z/\gamma^*(-\rightarrow ee) + \text{jet}(s)$



1.0 fb⁻¹

Compared to different LO ME +PS
Monte Carlo predictions



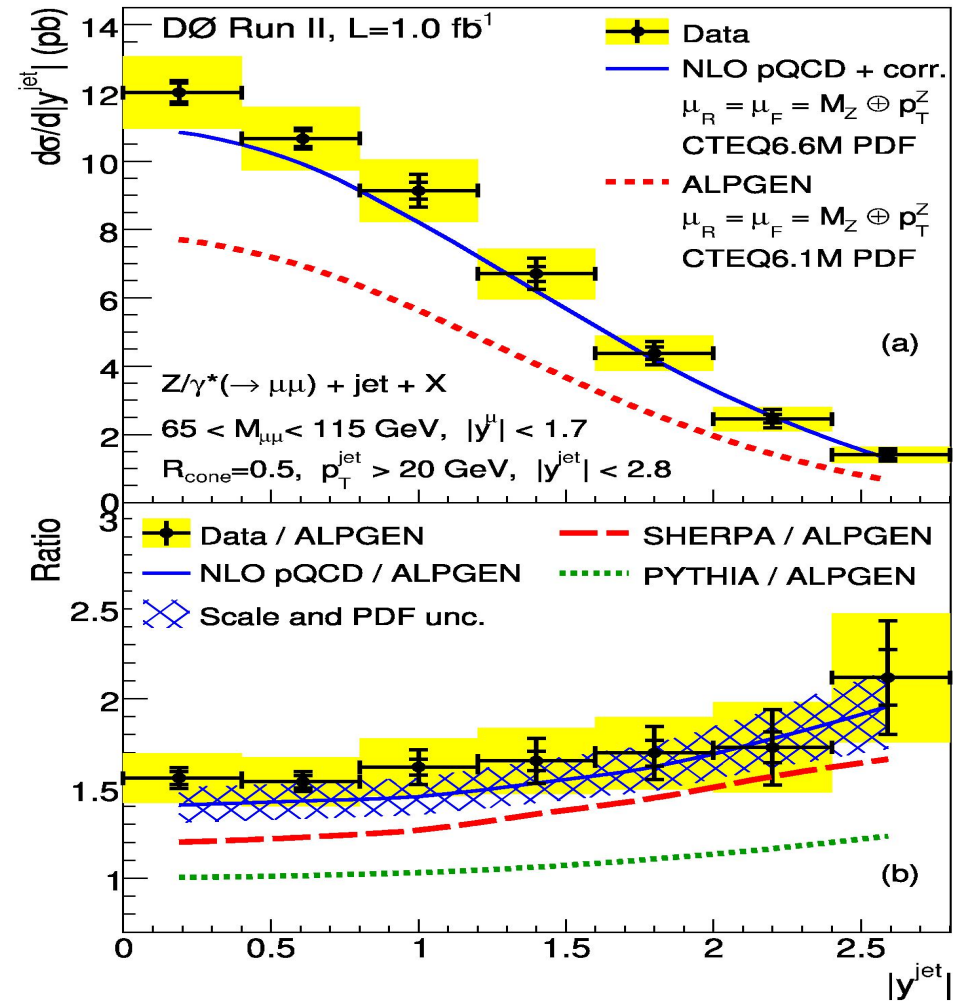
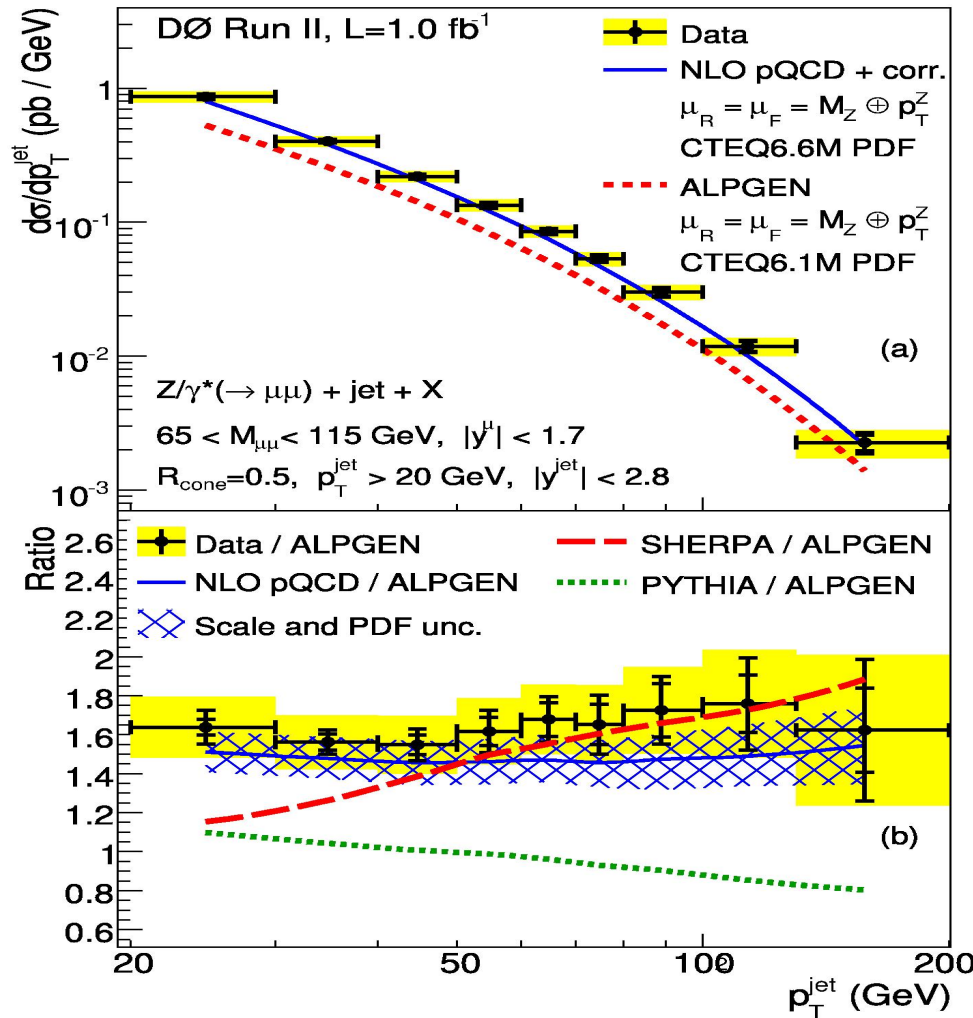
As expected PYTHIA and HERWIG too soft at large p_T
ALPGEN and SHERPA provide a better description of the shapes
Relatively large scale uncertainty illustrates a limited prediction power of the MCs
(but a lot of room for tuning them)



1.0 fb⁻¹

$Z/\gamma^*(-\rightarrow \mu\mu) + \text{jet}(s)$

PRL 669, 278 (2008)



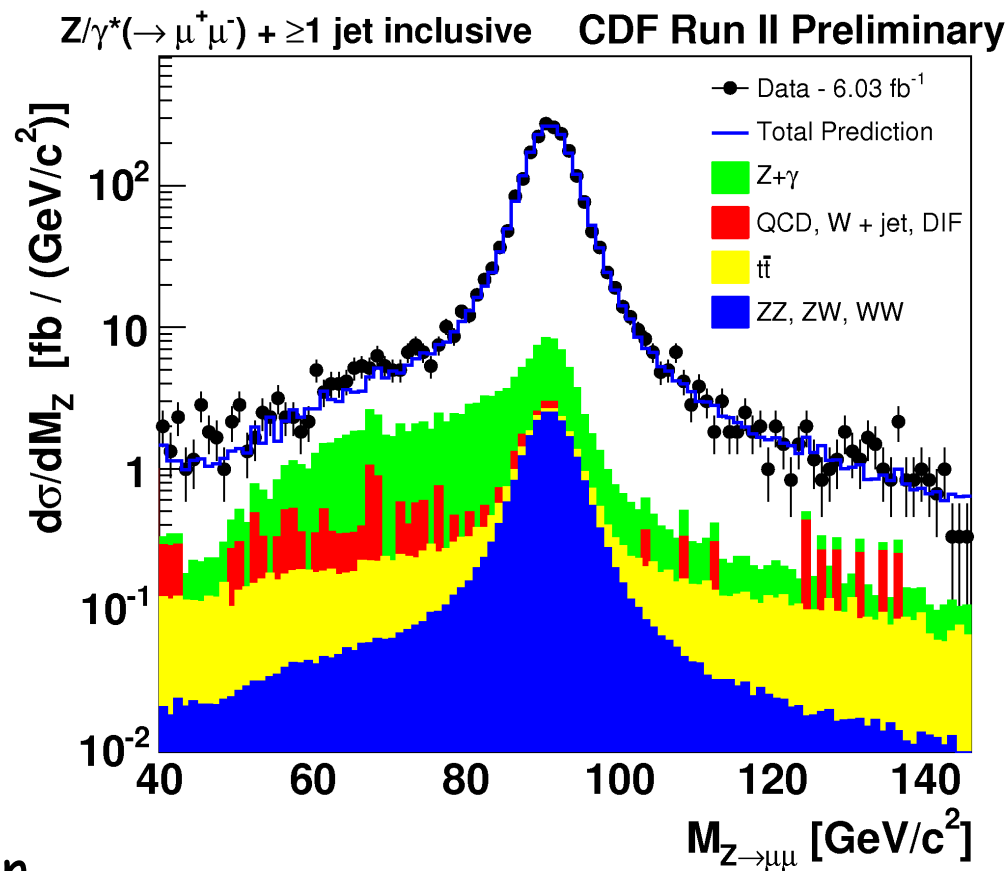
- Data described by NLO pQCD
- PYTHIA and ALPGEN below the data (consistent with LO prediction)
- SHERPA in between LO and NLO predictions (better at large Pt)



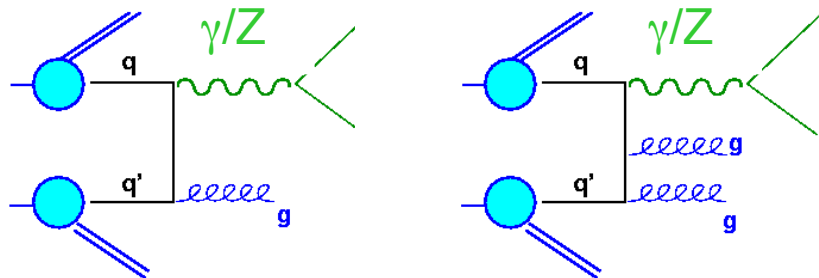
6.0 fb⁻¹

$Z/\gamma^*(-\rightarrow \mu\mu) + \text{jet}(s)$

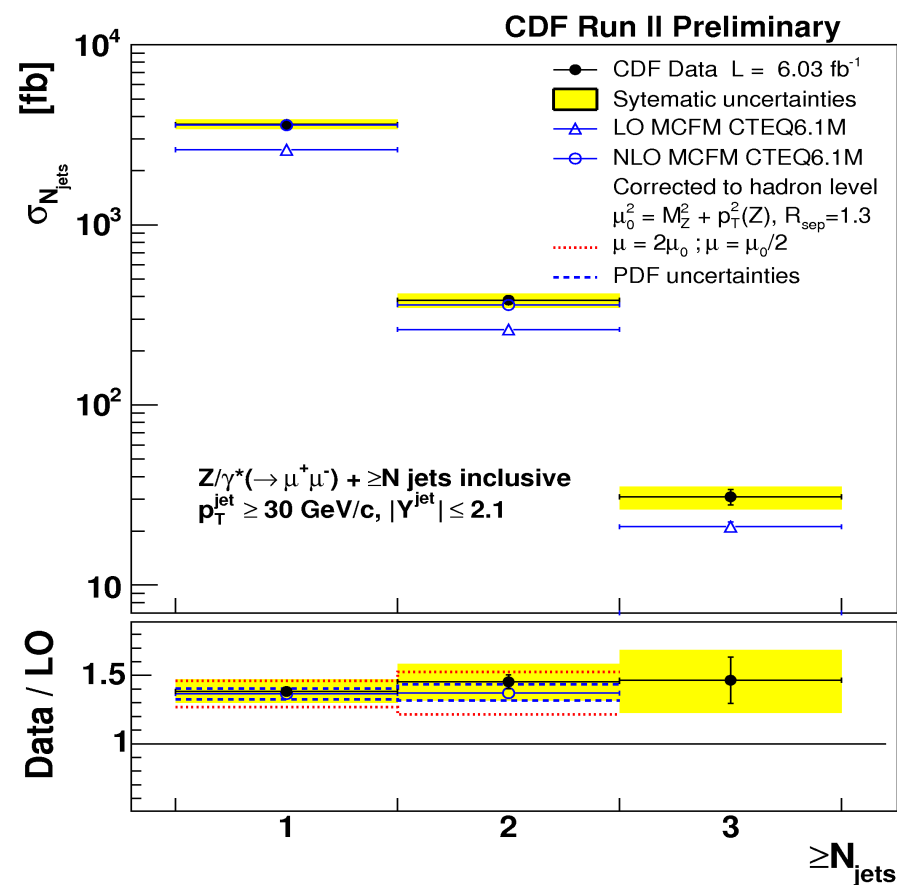
- CDF standard muon ID
 - $P_T > 25 \text{ GeV}$
 - $|\eta^1| < 1, |\eta^2| < 1$
 - $66 < M_{\mu\mu} < 116 \text{ GeV}/c^2$
- At least one jet MidPoint (R=0.7)
 - $P_T^{\text{jet}} > 30 \text{ GeV}/c$
 - $|\gamma^{\text{jet}}| < 2.1$
 - $\Delta R(\mu\text{-jet}) > 0.7$
- Follows the analysis in the electron channel with the aim for a future combination into a single result



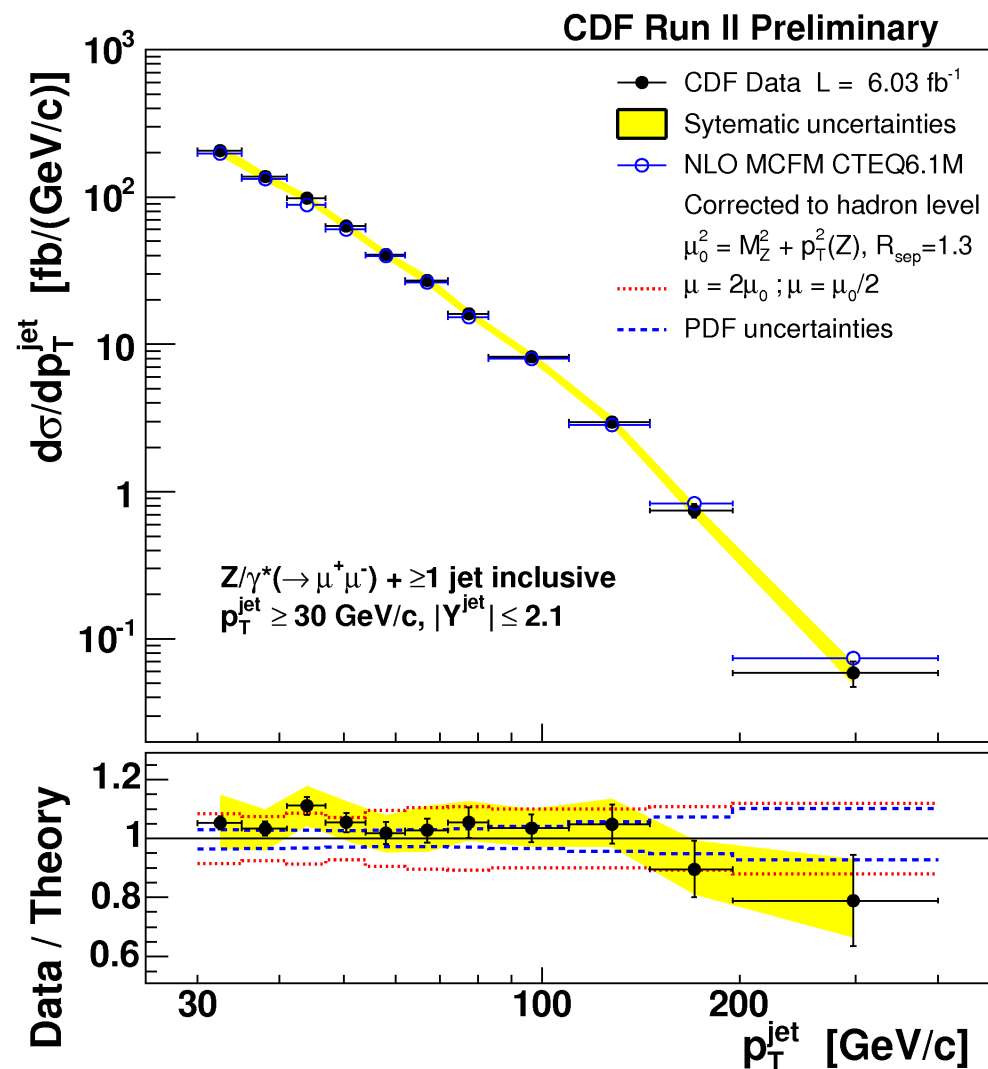
Background at the few % level



Inclusive $Z/\gamma^*(-\rightarrow \mu\mu) + 1 \text{ Jet}$



Good agreement with NLO pQCD (MCFM) predictions including non-pQCD corrections

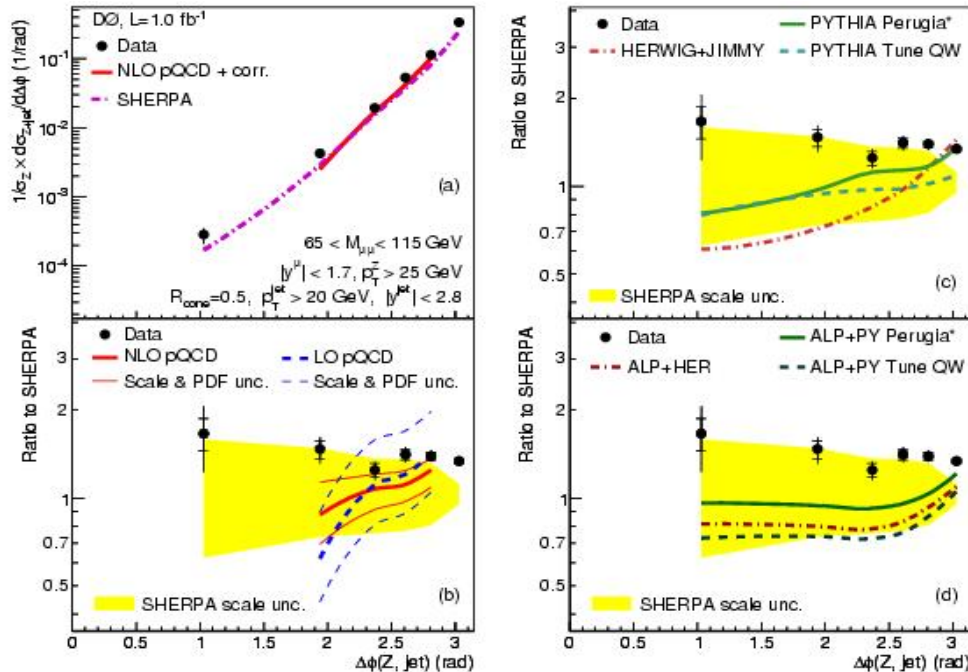


More to come along with the combination with electron channel

Z+jet angular distributions



PLB 682, 370 (2010)

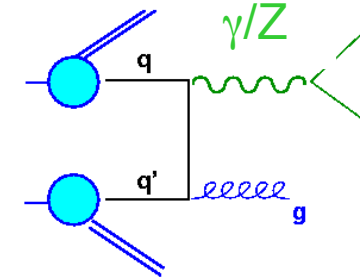


NLO pQCD provides a reasonable description of the data (maybe a bit low)

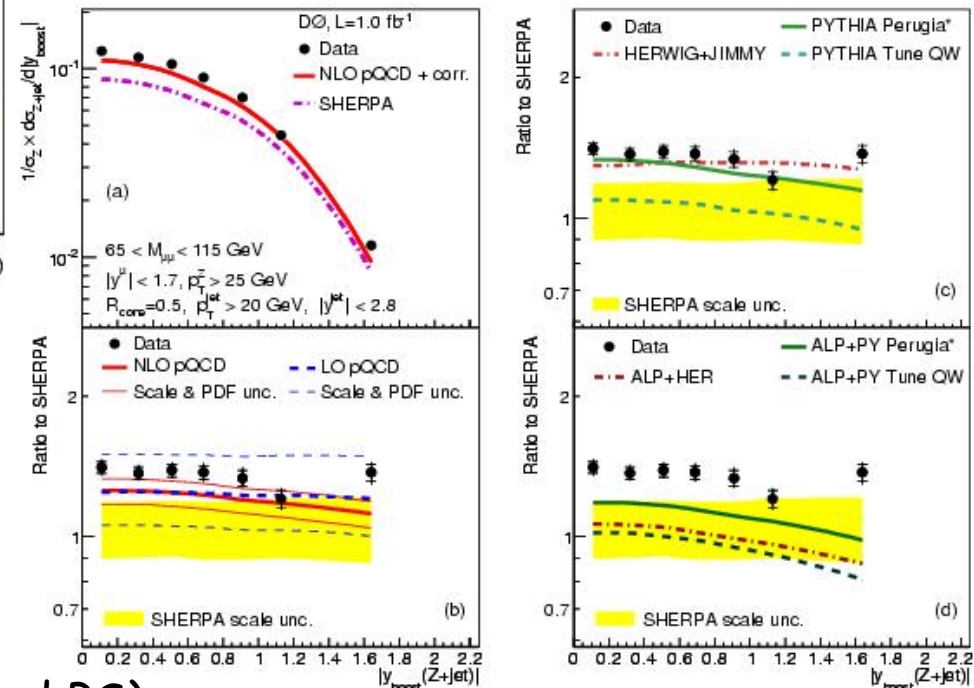
SHERPA provides the best description of the shape of the distributions

..followed by PYTHIA-Perugia* (pt-ordered PS)

→ Important observables for MC tuning



Differential cross sections as function of $\Delta\phi(z, \text{jet})$, $\Delta\eta(Z, \text{jet})$ and $y_{\text{boost}}(Z+\text{jet})$

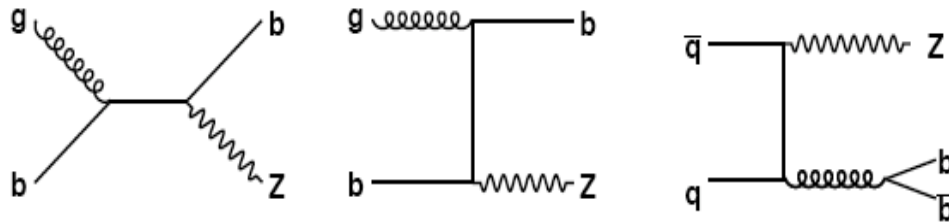




Phys.Rev.D79:052008,2009

2 fb⁻¹

Inclusive Z+b



$$\frac{\sigma^{\text{jet}}(Z + b \text{ jet})}{\sigma(Z)} = \frac{N^{\text{jet}}(Z + b \text{ jet})/N(Z)}{\epsilon^{\text{jet}}(Z + b \text{ jet})/\epsilon(Z)}$$

Considering electron and muon channels

$$76 < M_{\parallel} < 106 \text{ GeV}$$

(eff. 41% for $Z \rightarrow ee$, 23% for $Z \rightarrow \mu\mu$)

Jets with $E_t > 20 \text{ GeV}$ and $|\eta| < 1.5$

(JETCLU R=0.7)

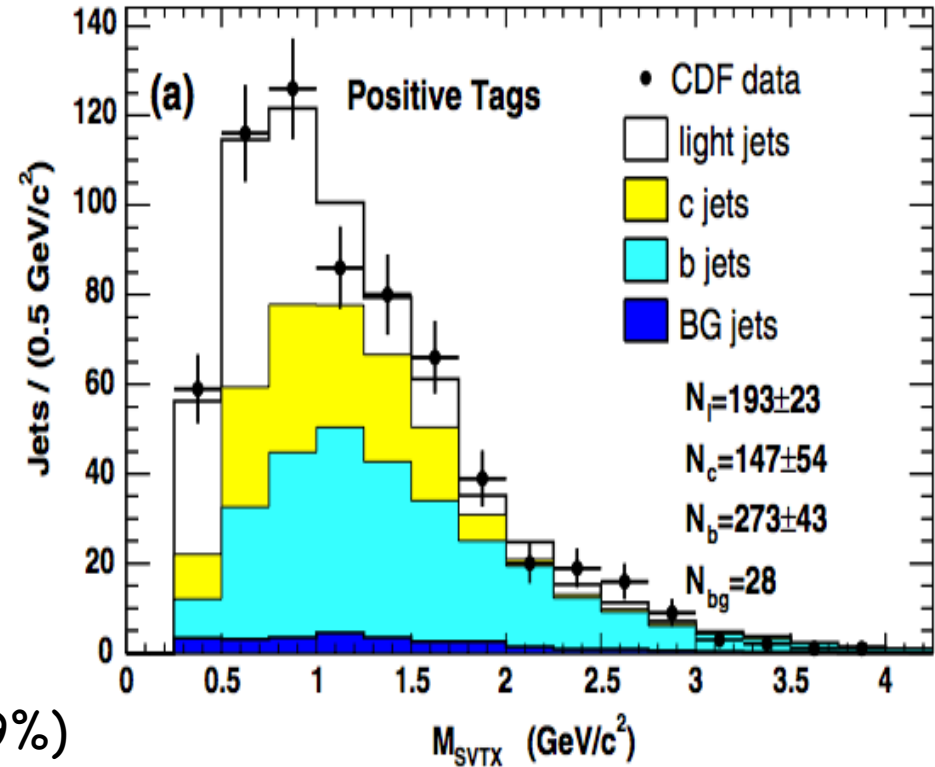
At least one jet b-tagged (eff. Z+b-jet : 9%)

(b-jet fraction from fit to vertex mass)

Background from other

physics processes taken from MC

non-pQCD corrections applied to MCFM : +8%

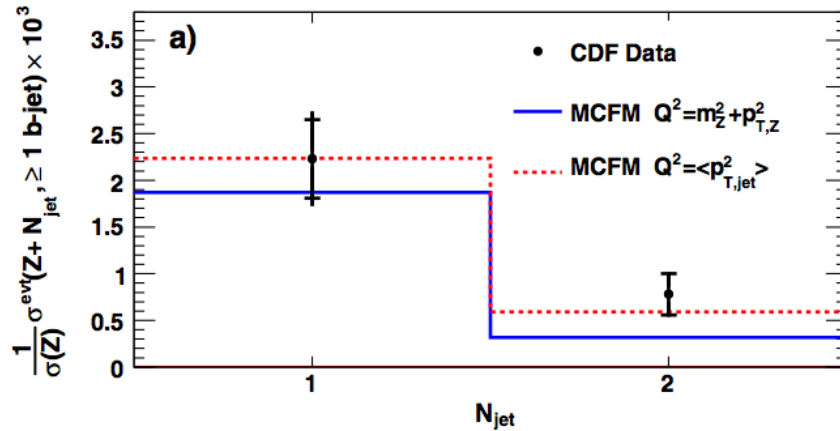
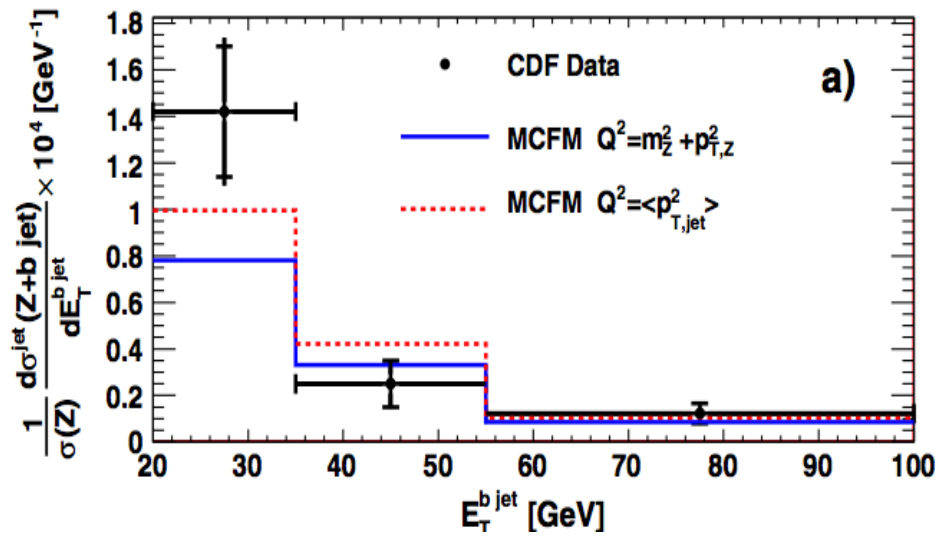


$$\frac{\sigma^{\text{jet}}(Z + b \text{ jet})}{\sigma(Z)} = (3.32 \pm 0.53(\text{stat}) \pm 0.42(\text{syst})) \times 10^{-3}$$

$$\text{MCFM} : 2.3 \times 10^{-3} (Q^2 = M_Z^2 + P_{T,Z}^2)$$

$$: 2.8 \times 10^{-3} (Q^2 = \langle P_{T,\text{Jet}}^2 \rangle)$$

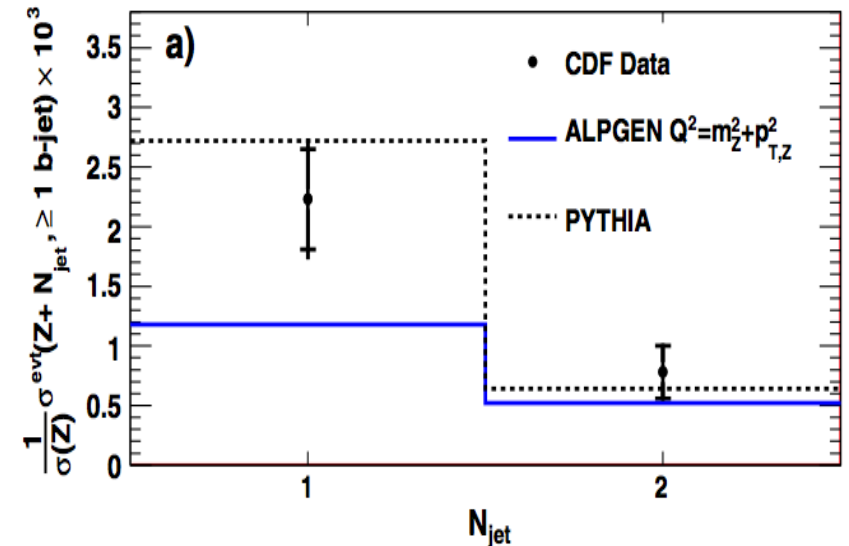
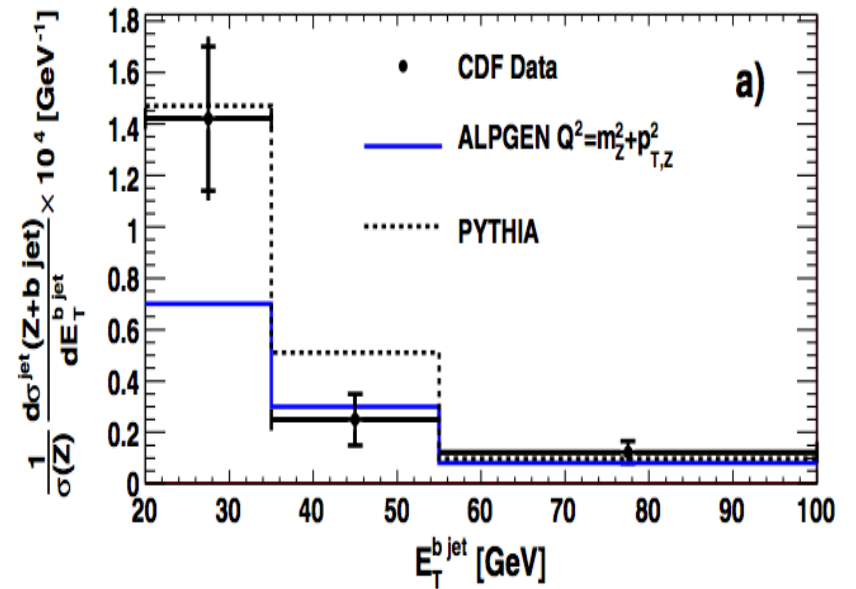
Z+b



$$\frac{\sigma(Z+b)}{\sigma(Z+\text{jets})} = 2.08 \pm 0.33 \pm 0.34(\%)$$

MCFM: 1.8% ($Q^2 = M_Z^2 + P_{T,Z}^2$); 2.2% ($Q^2 = \langle P_{T,\text{Jet}}^2 \rangle$)

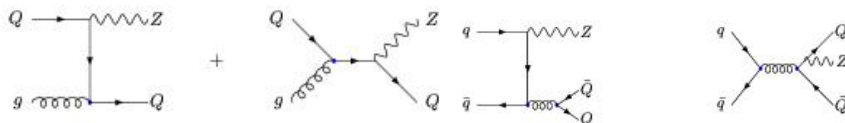
Measurements in agreement with predictions
(large uncertainties in both data and theory)



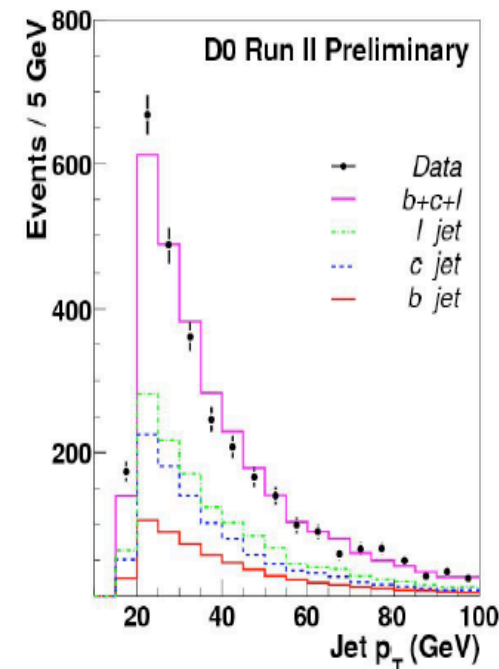
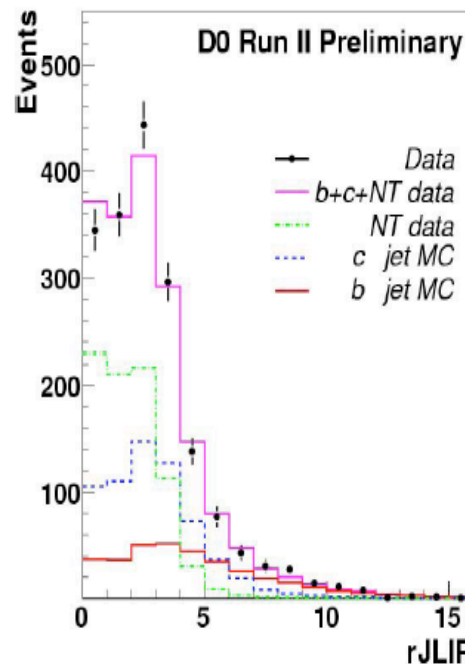
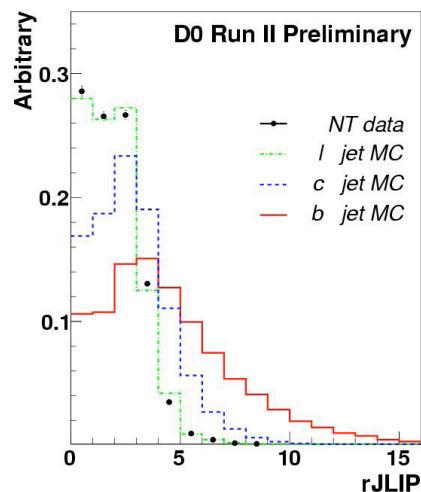
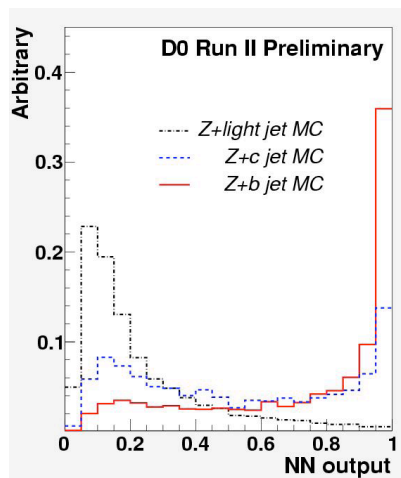
Also large variations between PYTHIA and ALPGEN

4.2 fb⁻¹

Z+b Production



$p_T > 20 \text{ GeV}, |\eta| < 1.1$



Using NN to reduce light-flavor component and a likelihood fit to extract the Z+b signal

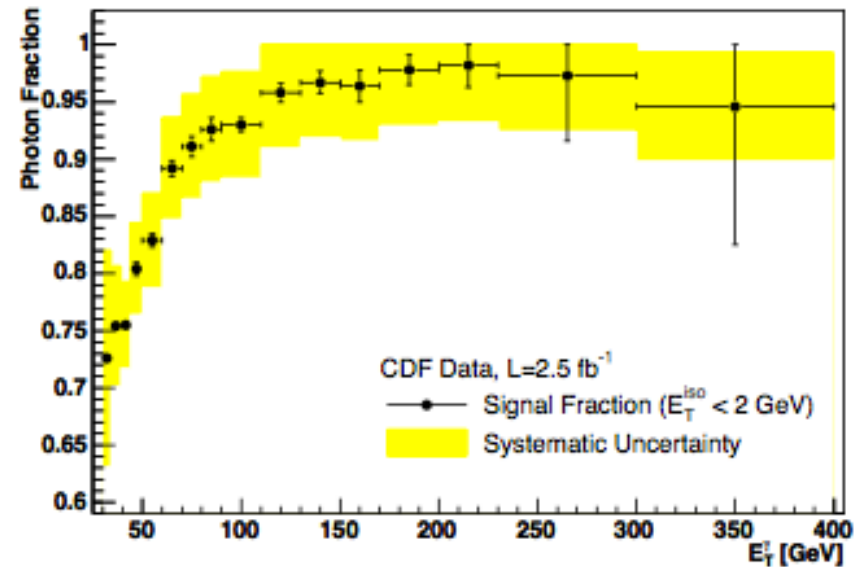
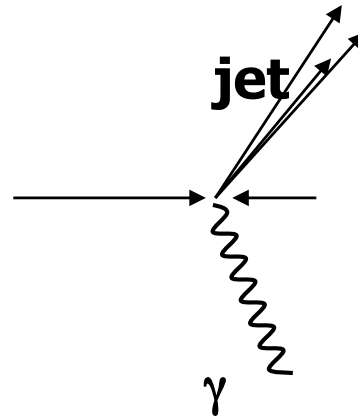
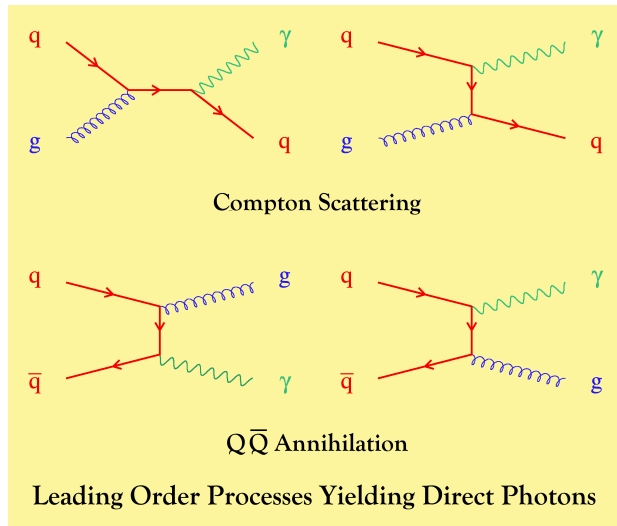
Z+b fraction	0.191 ± 0.030
Z+c fraction	0.384 ± 0.072
Z+light jet fraction	0.424 ± 0.054
$\sigma(\text{Z+b})/\sigma(\text{Z+jet})$ NLO/MCFM	$0.0176 \pm 0.0024 \text{ (stat)} \pm 0.0023 \text{ (syst)}$ 0.0184 ± 0.0022

MCFM describes the data

Templates for b and charm from MC ALPGEN

Light flavor template from data negative NN tags)

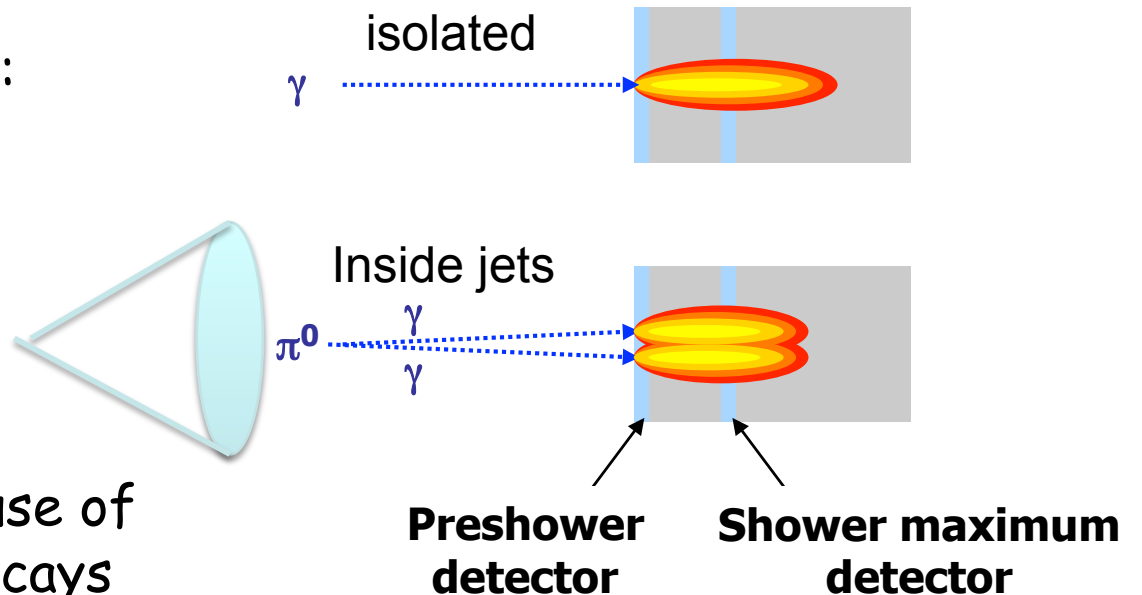
Prompt Photon Production



Using prompt photons one can precisely study QCD dynamics:

- Well known coupling to quarks
- Give access to lower P_t
- Clean: no need to define "jets"
- constrain of gluon PDF

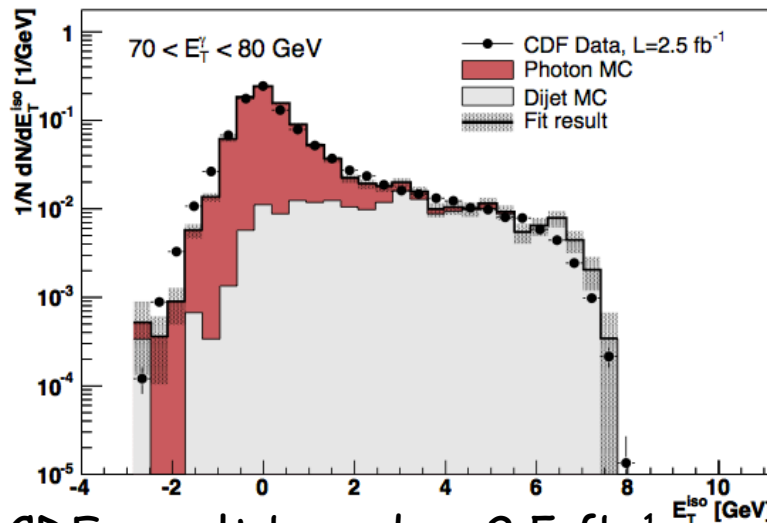
Experimentally difficult because of large background from π^0 decays





Inclusive Prompt Photon

Isolated photons (E_T in $R=0.4 < 2$ GeV)
 $P_T > 30$ GeV/c, $|\eta| < 1.0$

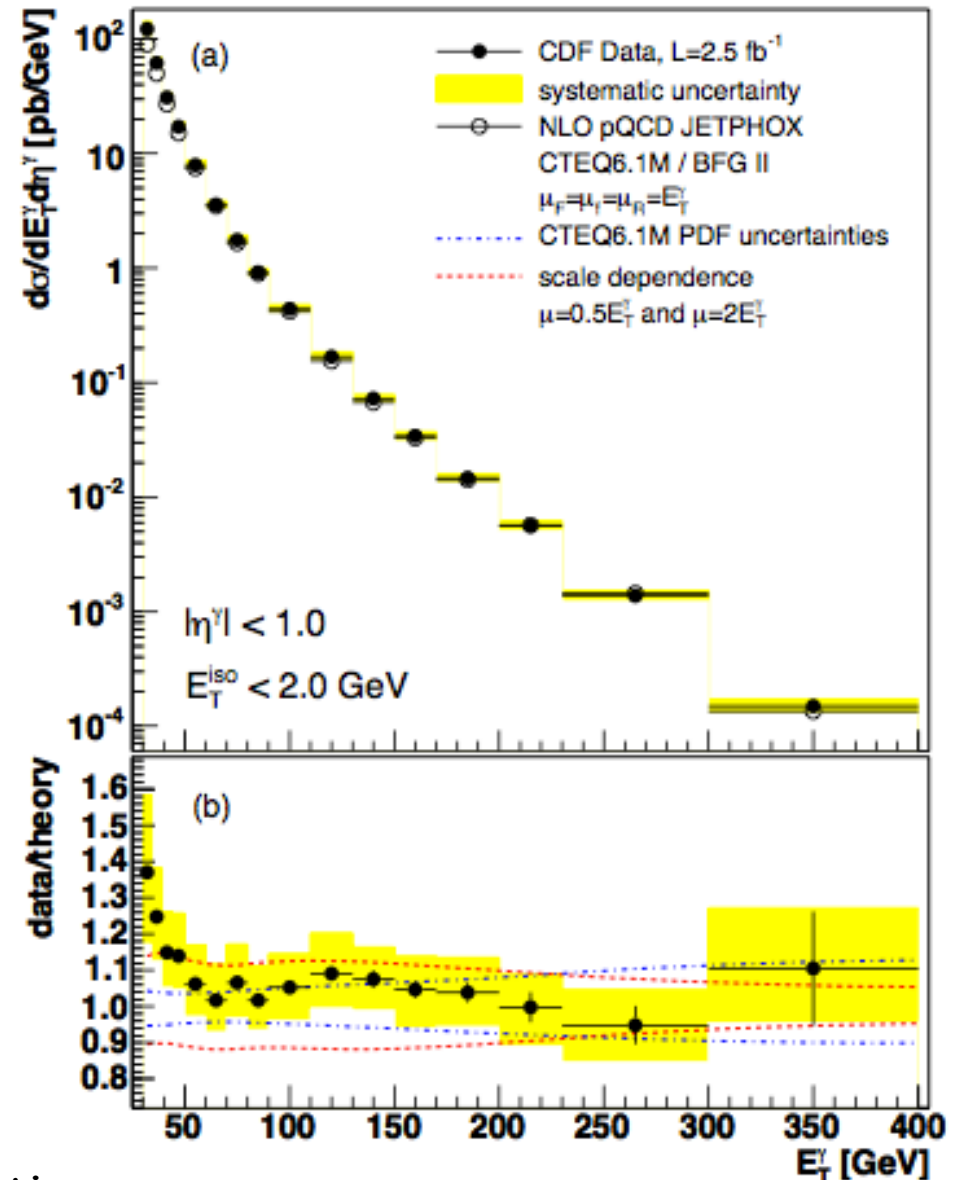


New CDF result based on 2.5 fb^{-1}

Agreement with NLO pQCD
 (similar known shape at low P_T)

The NLO pQCD prediction is corrected
 for non-pQCD effects from the UE
 affecting the isolation

→ 10% reduction of theoretical cross section..





γ +jets results

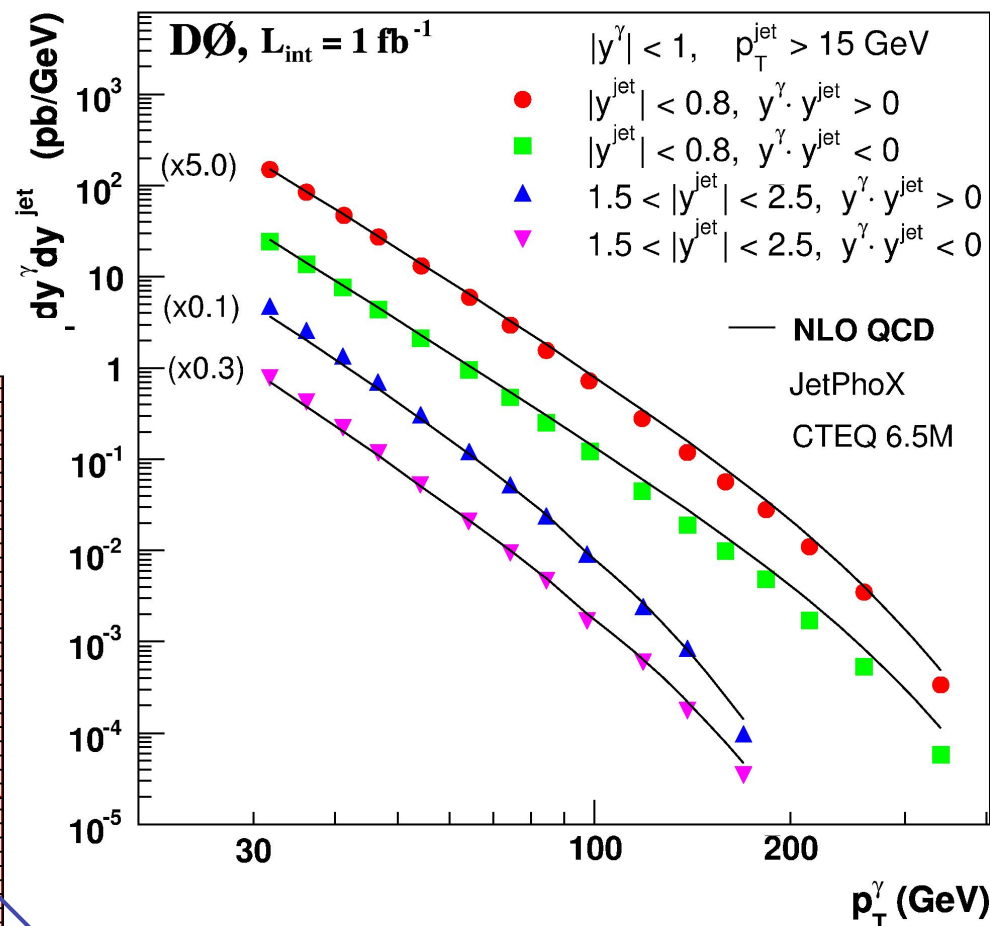
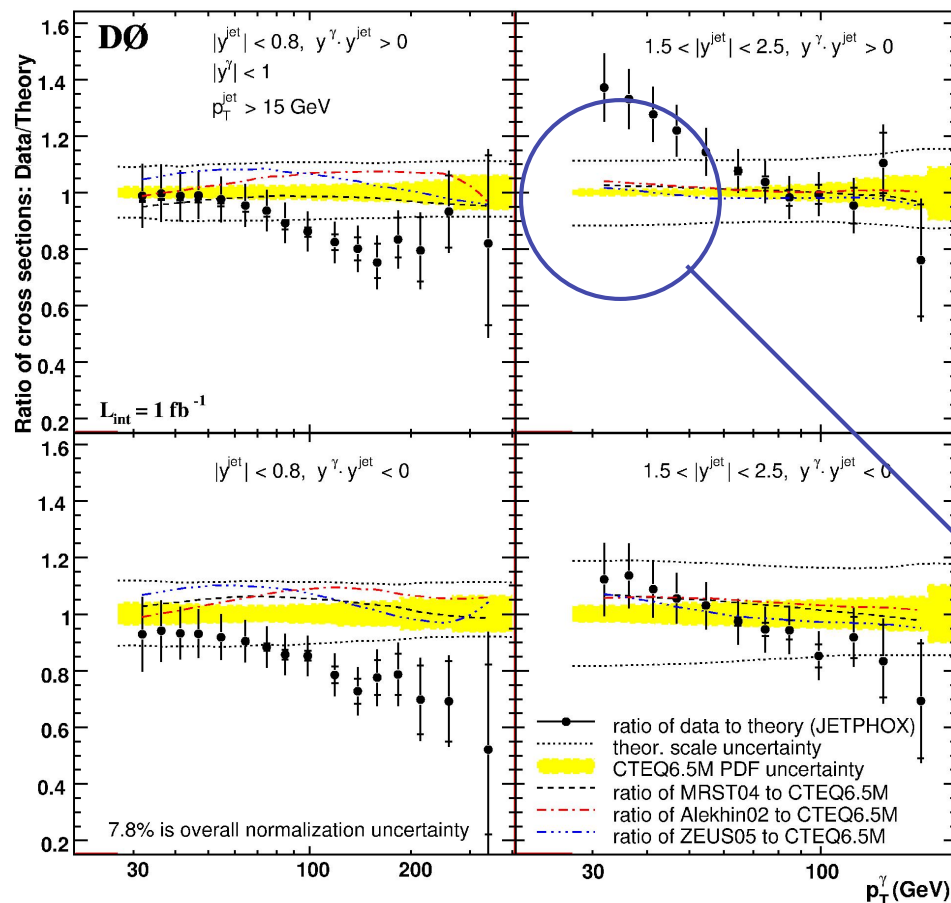
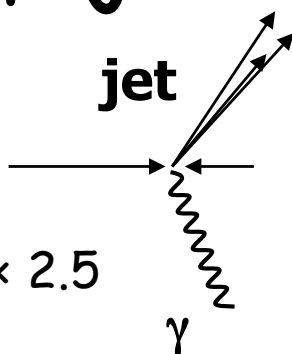
PLB 666, 2435 (2008)

Isolated photons

$P_{T\gamma} > 30 \text{ GeV}/c$, $|\eta| < 1.0$

Jets with $P_{Tj} > 15 \text{ GeV}/c$

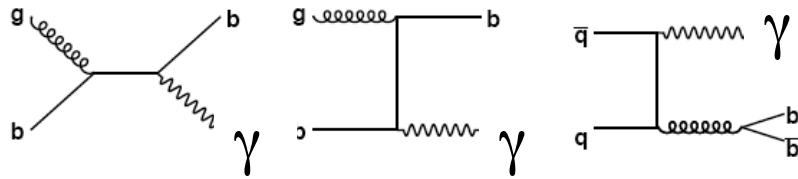
$|\eta^{\text{jet}}| < 0.8$ or $1.5 < |\eta^{\text{jet}}| < 2.5$



NLO pQCD prediction not really able to follow the data in some regions of the photon-jet phase space...

Very interesting for theorist if CDF could provide similar results...

PRL 102, 192002 (2009)

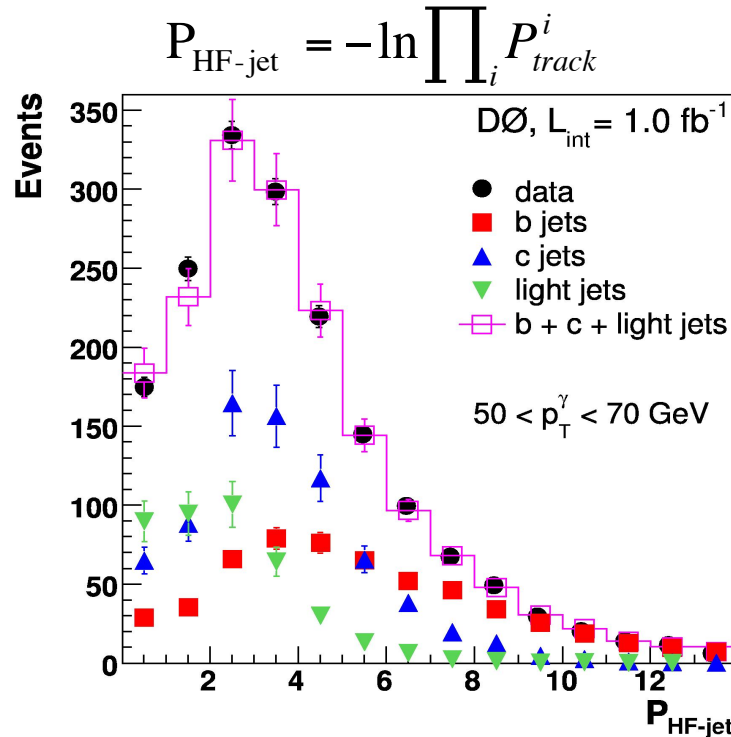


Isolated photons

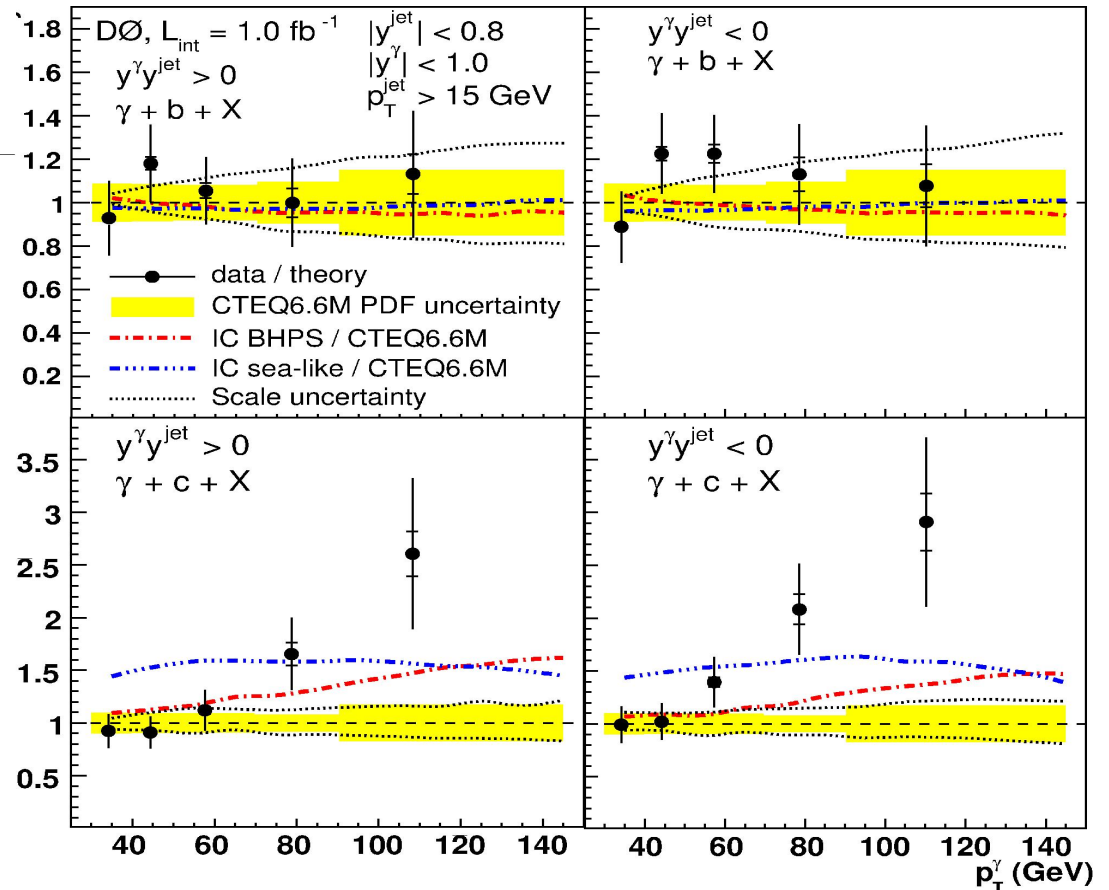
$P_T > 30 \text{ GeV}/c$, $|\eta| < 1.0$

Jets with $P_T > 15 \text{ GeV}/c$, $|\eta^{\text{jet}}| < 0.8$

Light quark suppressed using NN
Separation of light/b/c based on



$\gamma + b/c$



Good agreement with NLO pQCD for $\gamma+b$

Disagreement for $\gamma+c$ at large P_T

- Not covered by models with intrinsic charm
- Maybe related to $\gamma + \text{gluon} \rightarrow Q\bar{Q}$ (which is dominant at large P_T)

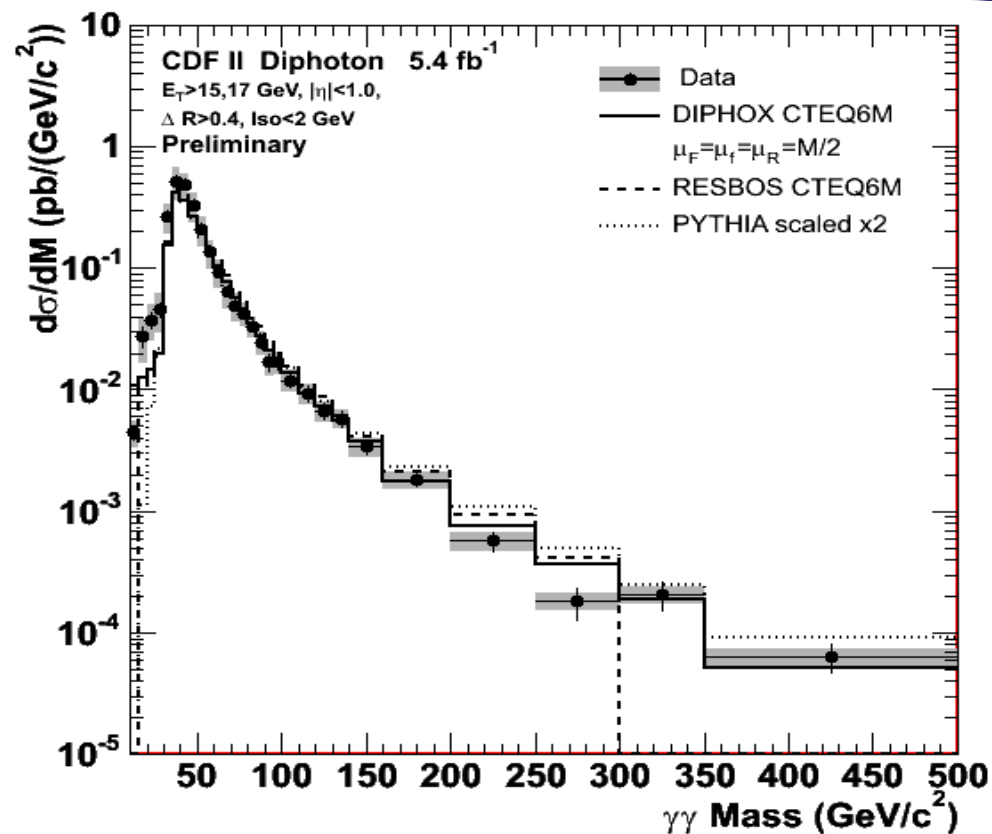
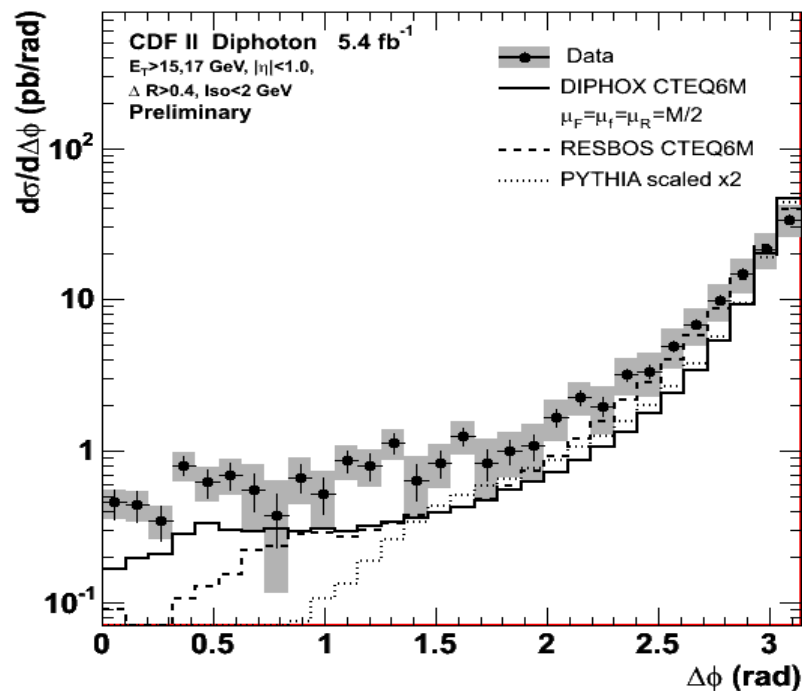
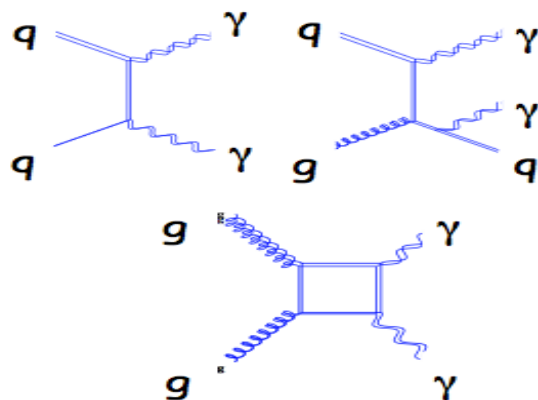
?

5.4 fb⁻¹

Di-photon Production



Very relevant for Higgs, SUSY, ED searches



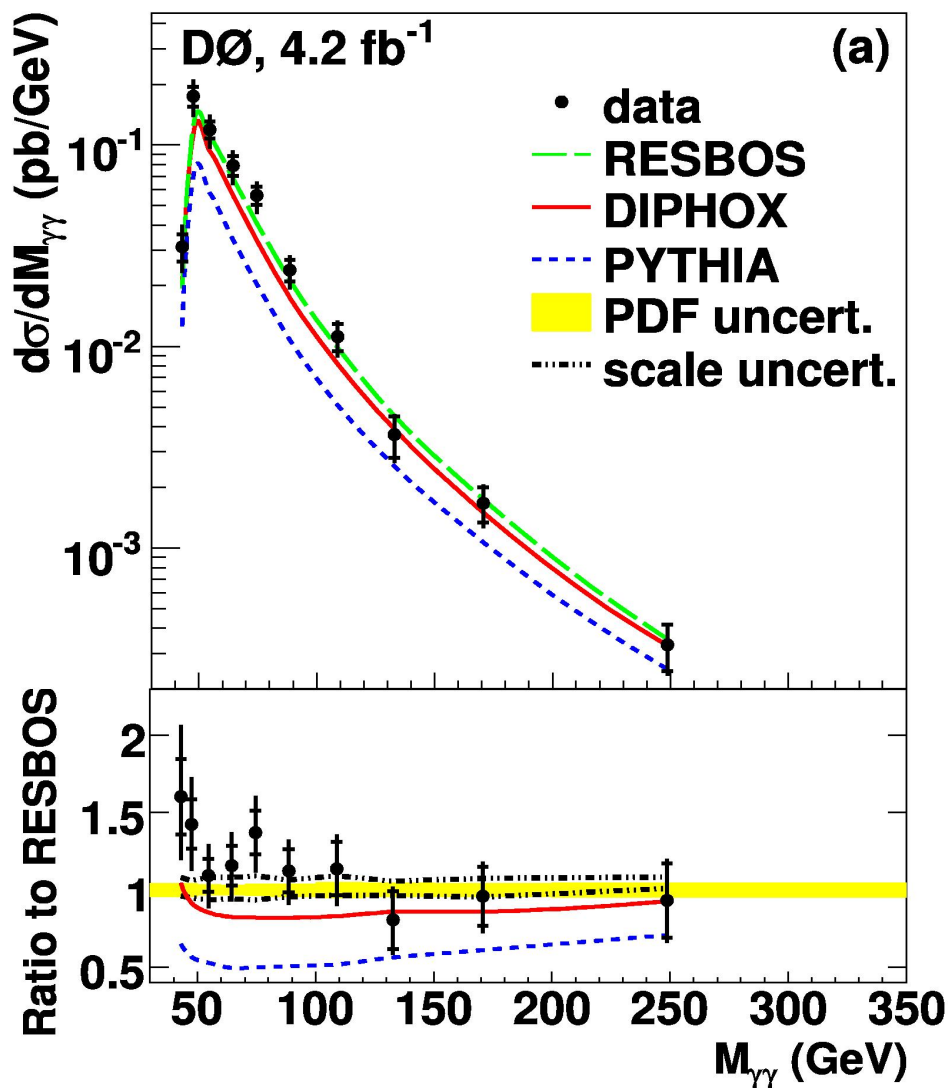
Measured cross sections for central isolated photons compared to

- PYTHIA (LO ME + PS) (x2 scaled)
- RESBOS (NLO + re-summed soft ISR)
- DIPHOX (NLO ... only LO for $gg \rightarrow \gamma\gamma$)

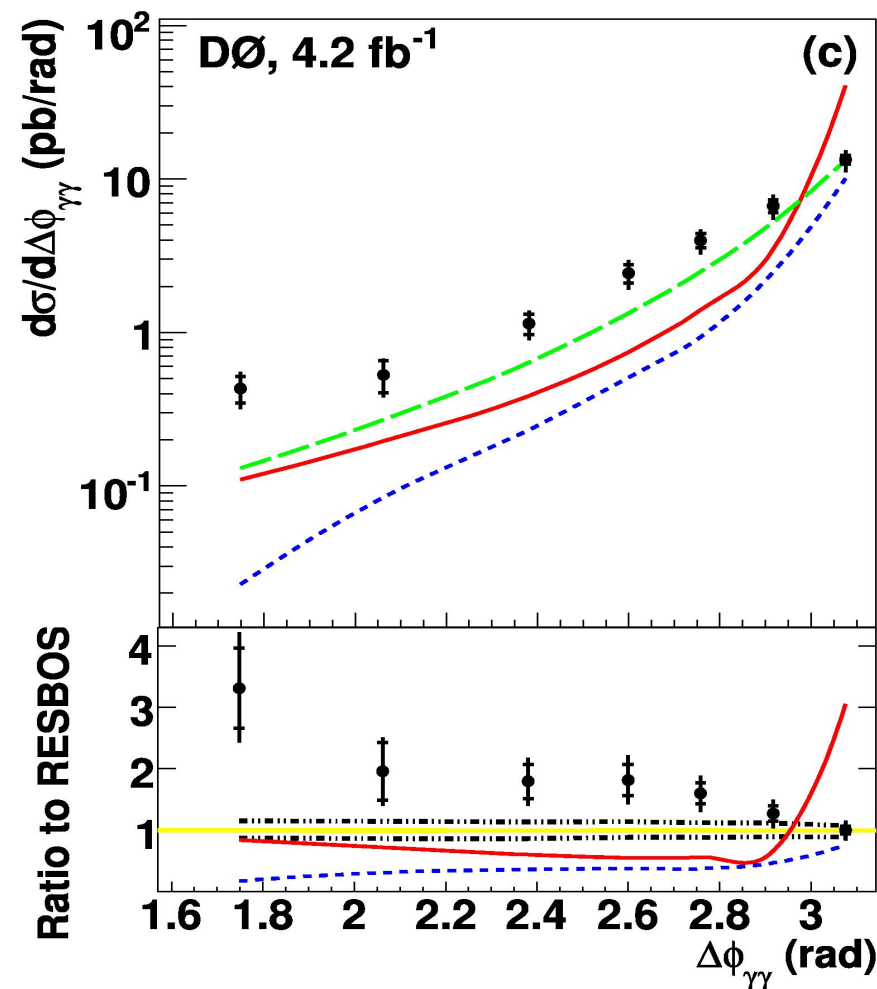
None of them describe the data well....

4.2 fb⁻¹

Di-photon Production



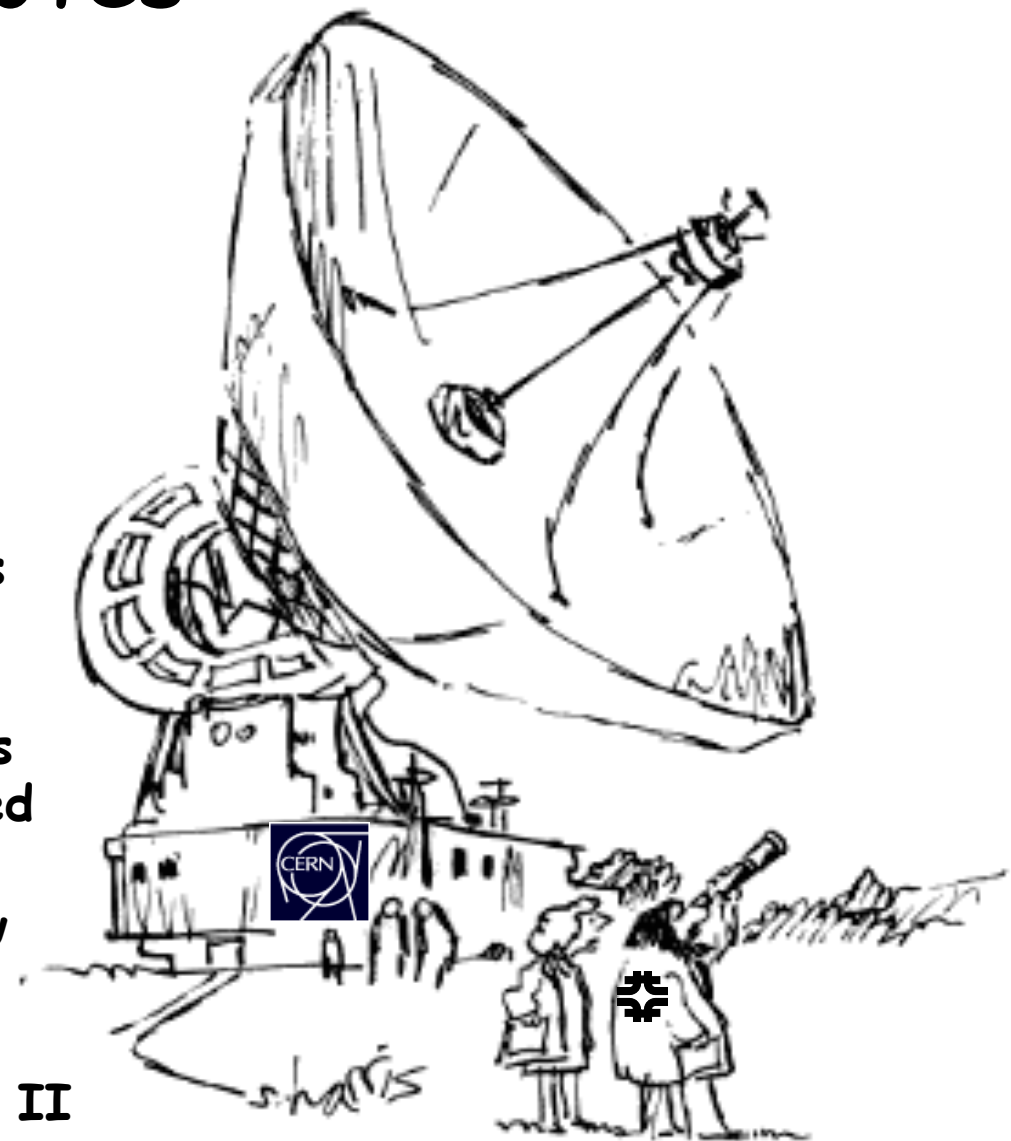
RESBOS closer to the data but with large discrepancies at low $M_{\gamma\gamma}$ (low $P_{T}^{\gamma\gamma}$) and low $\Delta\phi^{\gamma\gamma}$



CDF and DØ results:
 Would indicate the need for NNLO terms
 and the importance of the proper
 treatment of fragmentation contributions

Final Notes

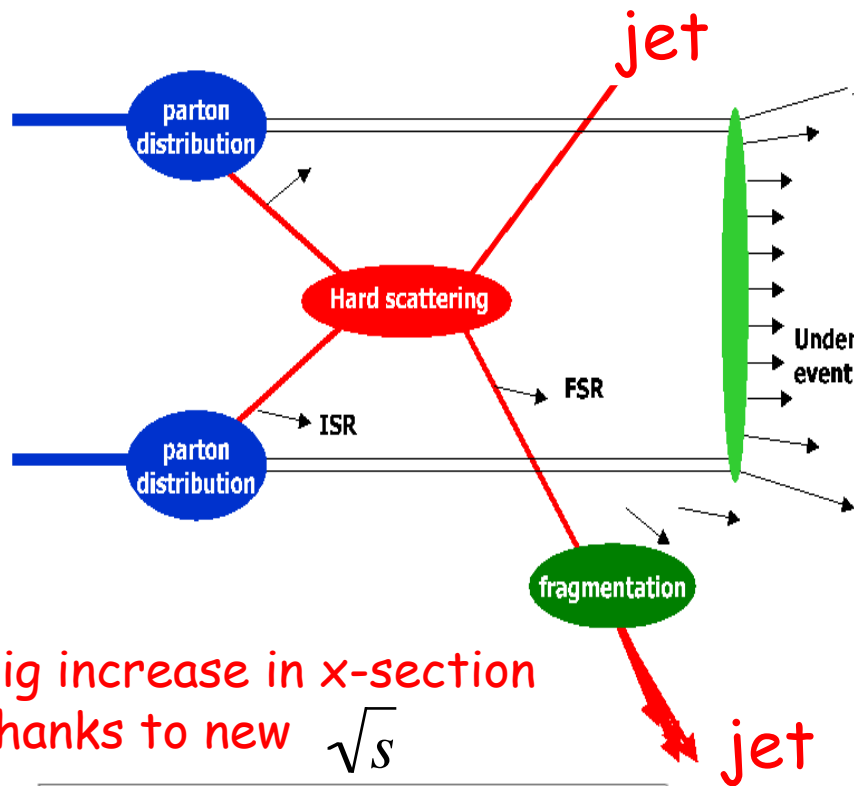
- Inclusive Jet measurements in Run II contributed to a better understanding of the gluon PDF
- NLO pQCD in general provides a good description of multi-jet data
- Z/W+jet(s) results test background estimations in searches for new physics
- First Z/W+HF measurements start challenging large theoretical uncertainties
→ More data and better predictions needed
- Photon + Jet and Diphoton results show some disagreements with pQCD NLO
- Tevatron promises 12 fb^{-1} by End Run II
- First LHC physics results by NOW



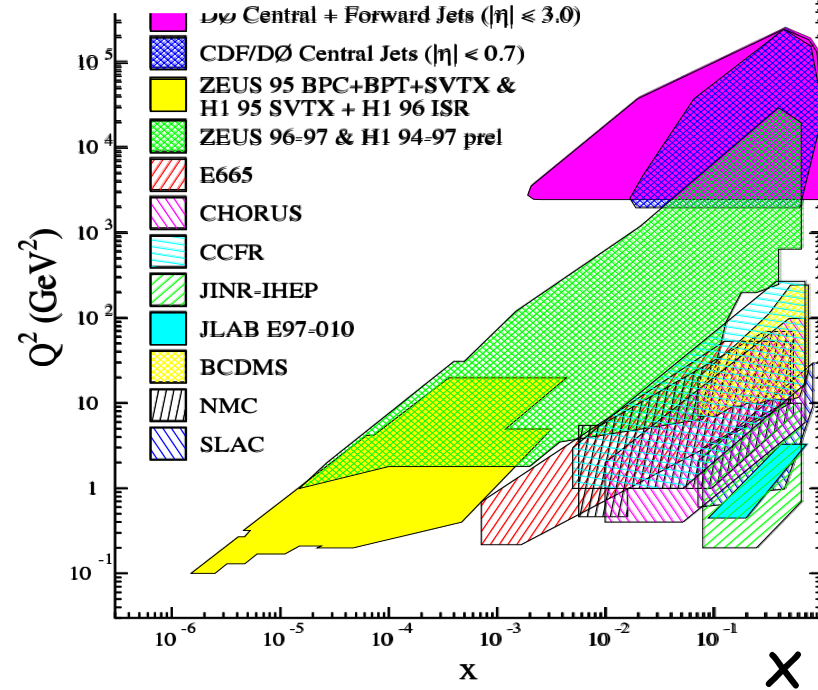
"Just checking."

Backup Slides

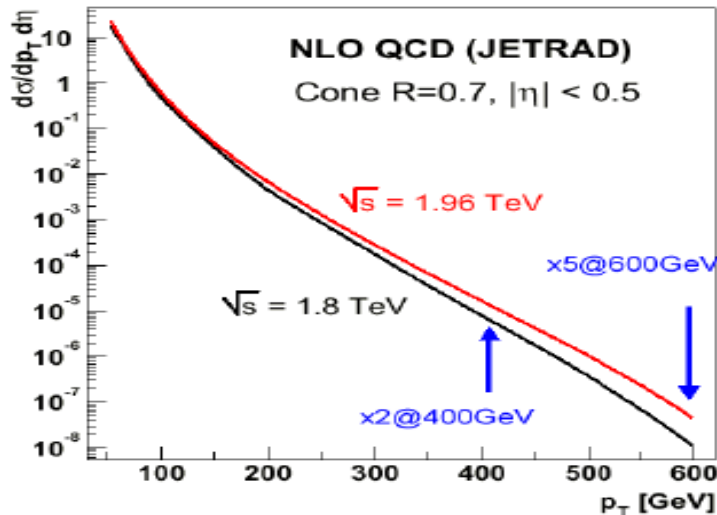
High Pt Jet Physics at 2 TeV



$Q^2 (\text{GeV}^2)$



Big increase in x-section thanks to new \sqrt{s}

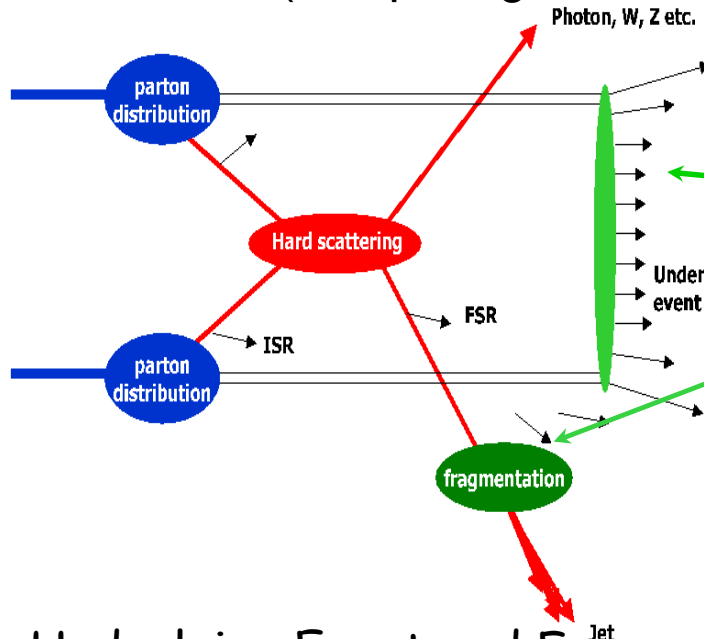


Huge step forward in Run II

- Pt range increased by 150 GeV/c
- Measurements in wide rapidity region
- Multi-jet cross sections
- Use of K_T and cone jet algorithms
- Inclusion of non-pQCD contributions

Non-pQCD contributions

(comparing data at hadron level with pQCD fixed order at parton level)

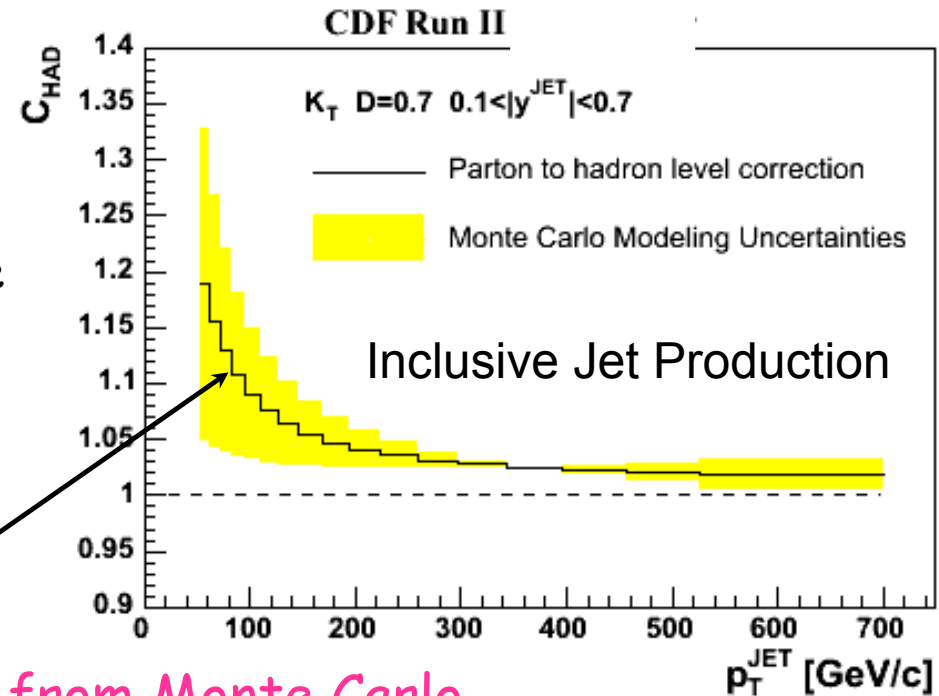


- Non-pQCD contributions
- Underlying Event
(remnant-remnant interactions)
- Fragmentation into hadrons

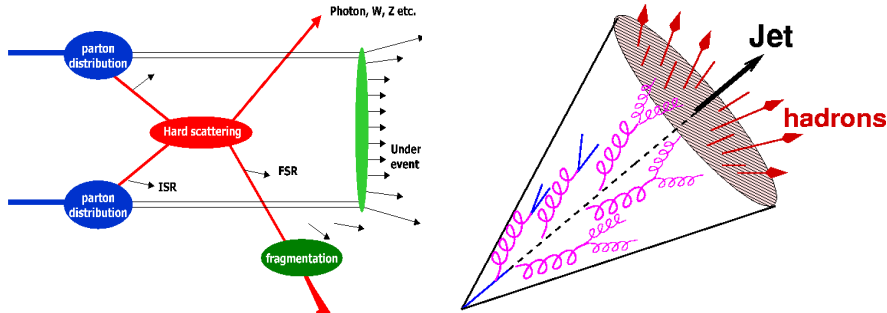
Underlying Event and Fragmentation contributions must be considered before comparing data to NLO QCD predictions
(only way to perform a fair comparison)

Precise measurements at low p_T require good modeling of the non-pQCD terms

parton-to-hadron corrections taken from Monte Carlo and applied to NLO pQCD predictions (data untouched)

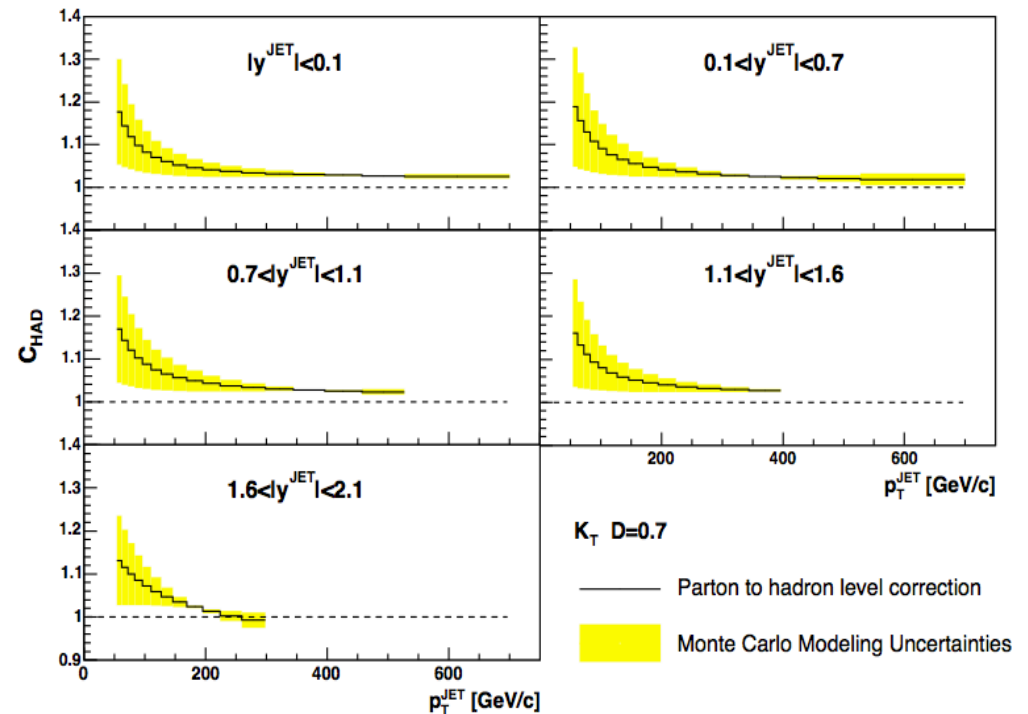
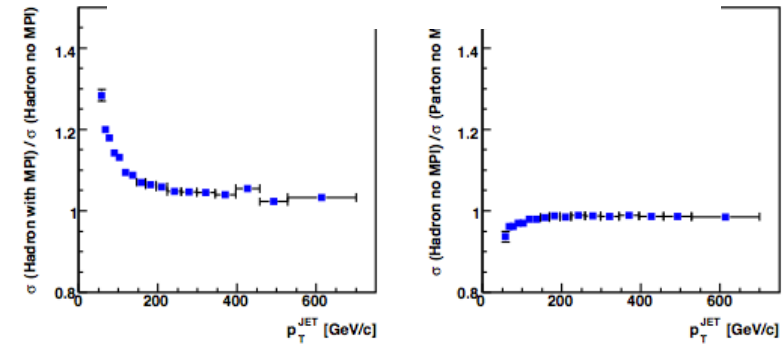


Underlying Event & hadronization Contribution



$$C_{\text{HAD}} = C_{\text{MPI}}^{\text{Hadron Level}} \times C_{\text{Frag}}^{\text{No MPI}}$$

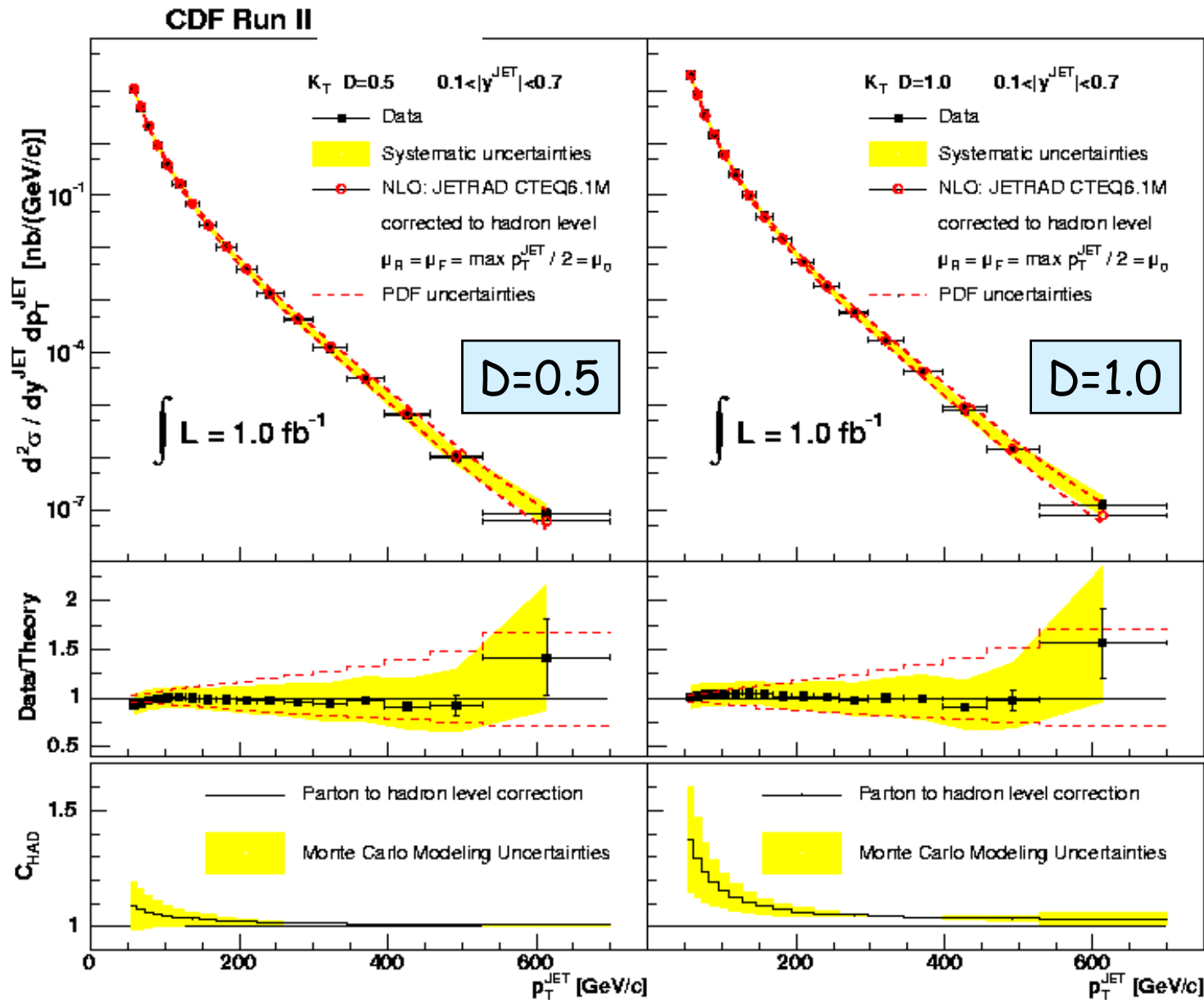
- Estimated using MC PYTHIA (and Herwig for systematics)
- Defined as the ratio of the generated distributions with/without UE and string fragmentation (Pythia)
$$C_{\text{HAD}}(p_T^{\text{jet}}, y^{\text{jet}}) = \frac{\sigma(\text{Hadron level with MPI})}{\sigma(\text{Parton level no MPI})}(p_T^{\text{jet}}, y^{\text{jet}})$$
- Applied to the parton-level fixed-order pQCD prediction
- The parton-to hadron factor comes with relatively large uncertainties due to dependence on the modeling
- Underlying Event dominates....



$$d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) \frac{\Delta R^2}{D^2}$$

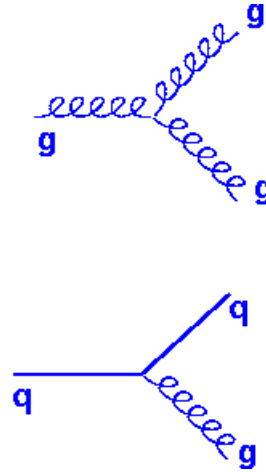
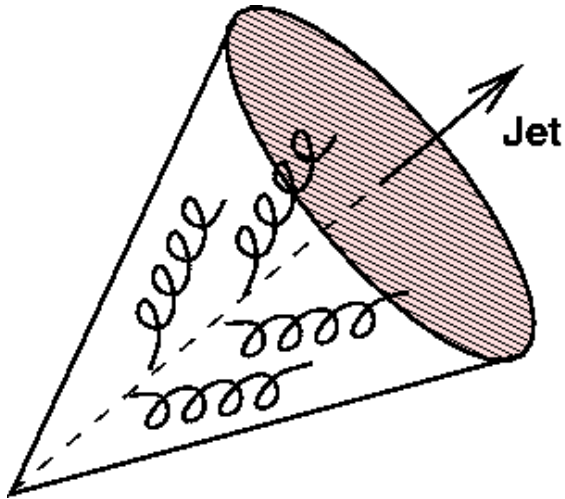
K_T Jets vs D

1 fb⁻¹



As D increases the required non-perturbative corrections increase at low P_T

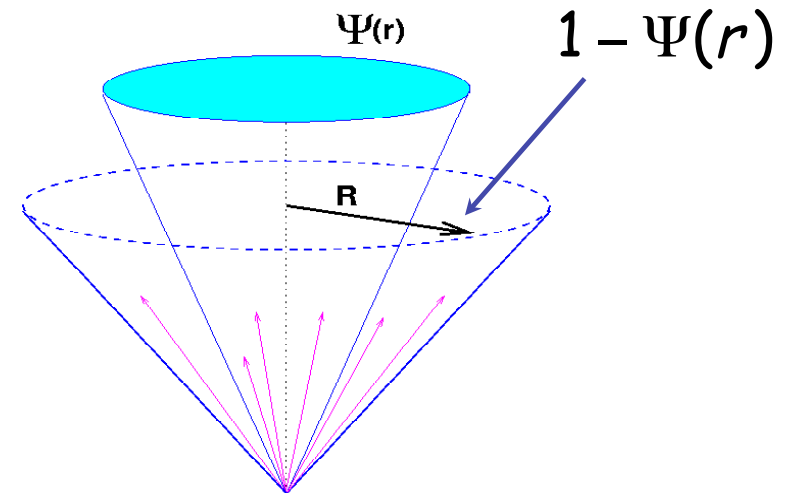
Jet Shapes



Gluons radiate more than quarks (QCD color charges)

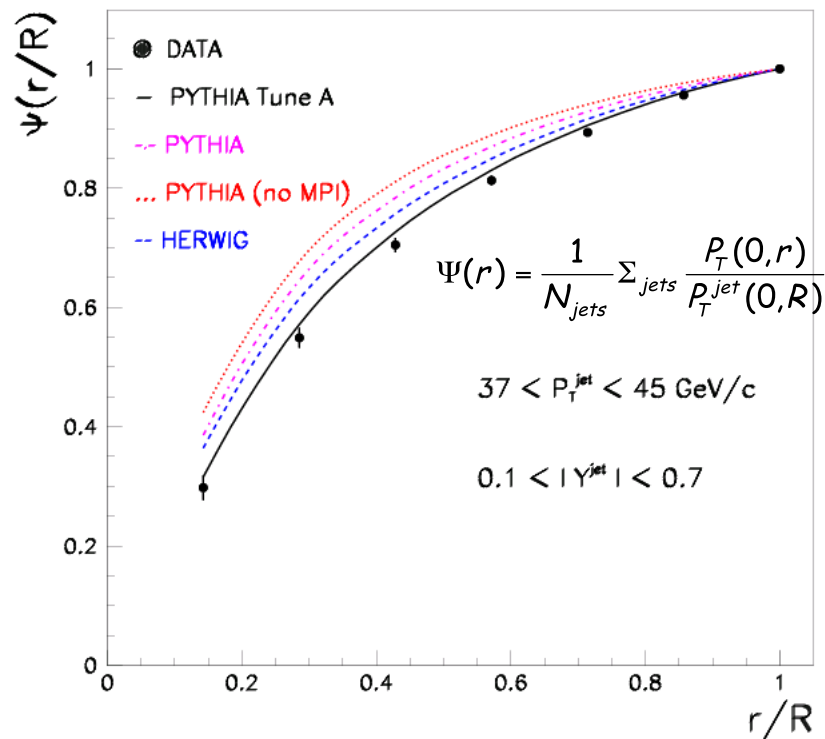
↓
Gluon jets Broader

- Jet shape dictated by multi-gluon emission from primary parton
- Test of parton shower models and their implementations
- Sensitive to underlying event structure in the final state

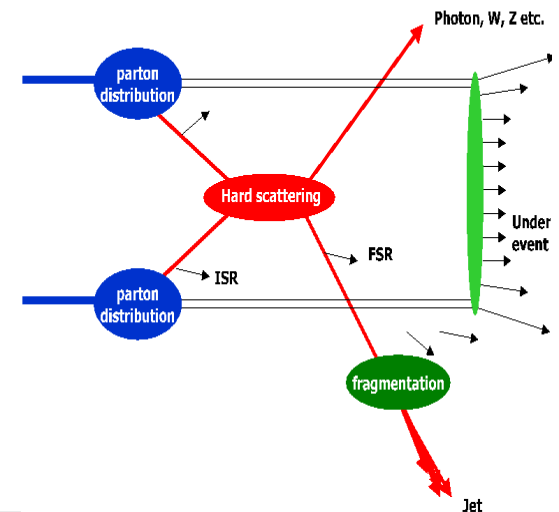
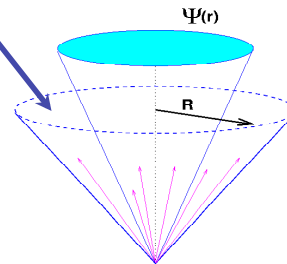


$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T^{jet}(0,R)}$$

Jet shapes

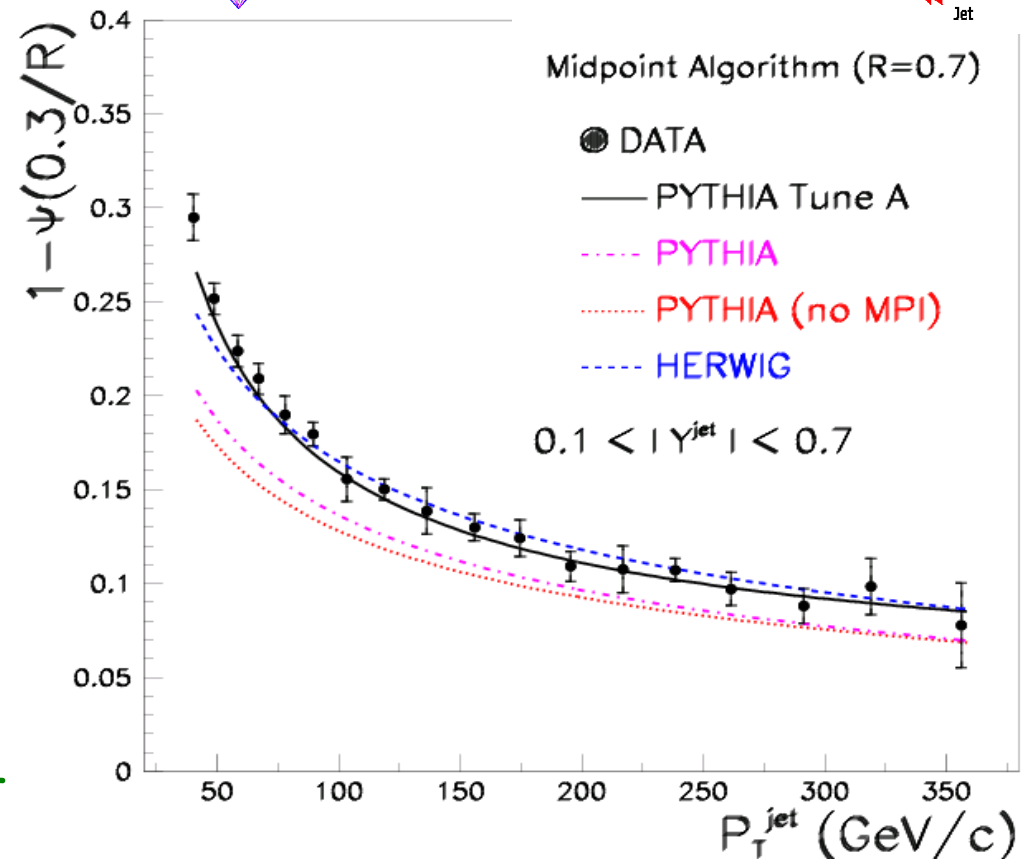


$1 - \Psi(r)$



- PYTHIA 6.2 Tune A describes the data (enhanced ISR + MPI tuning)
- PYTHIA 6.2 default too narrow
- MPI are important at low Pt
- HERWIG 6.4 too narrow at low Pt

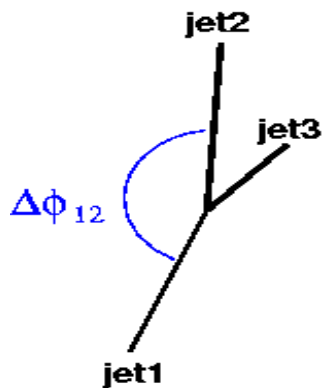
We know how to model the UE at 2 TeV for QCD jet processes



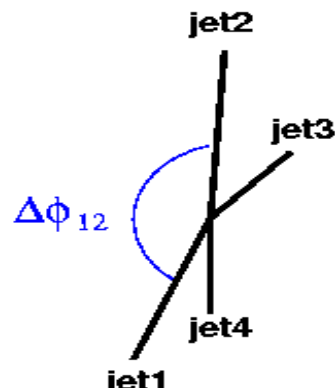


Studies on $\Delta\phi$ between jets

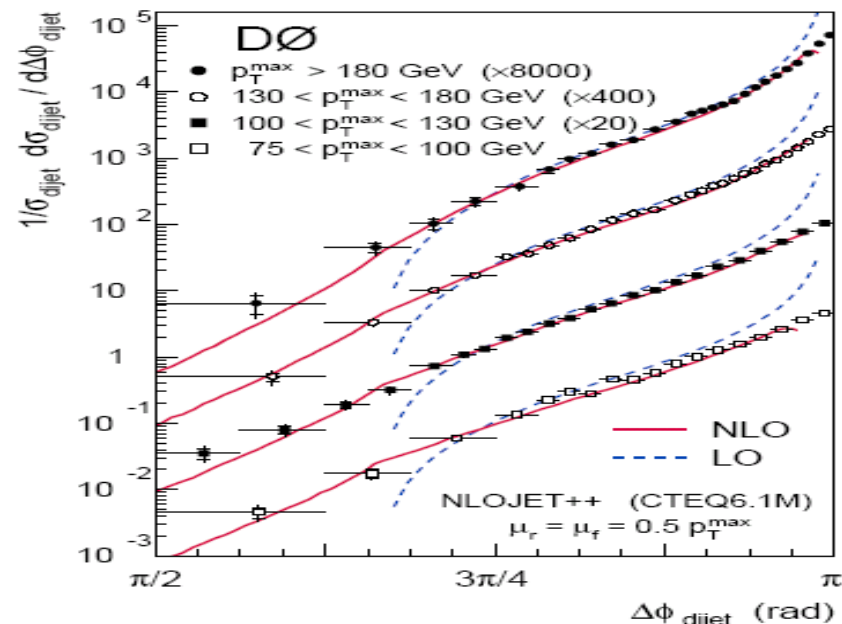
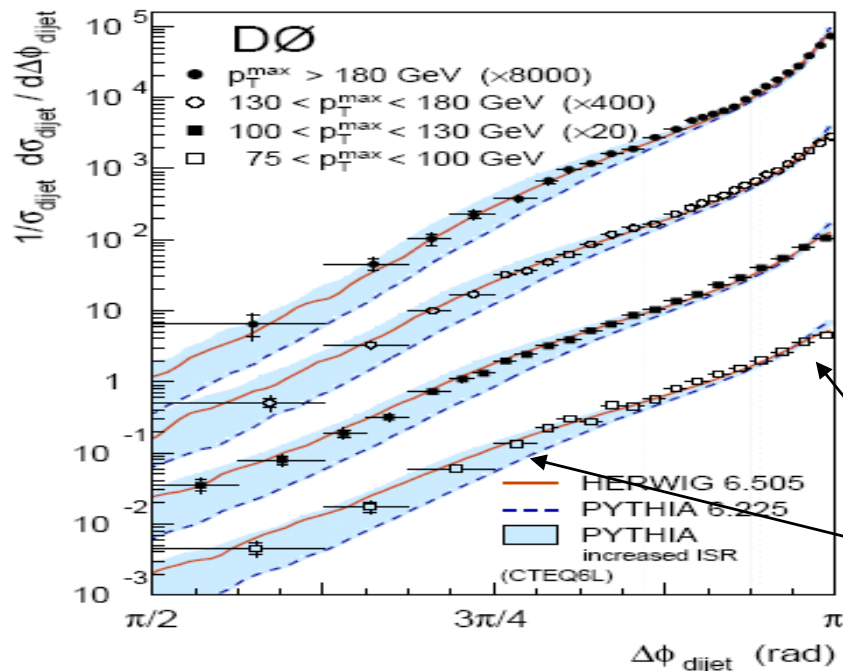
Using the Midpoint Jet Algorithm



LO in $\Delta\phi$



NLO in $\Delta\phi$

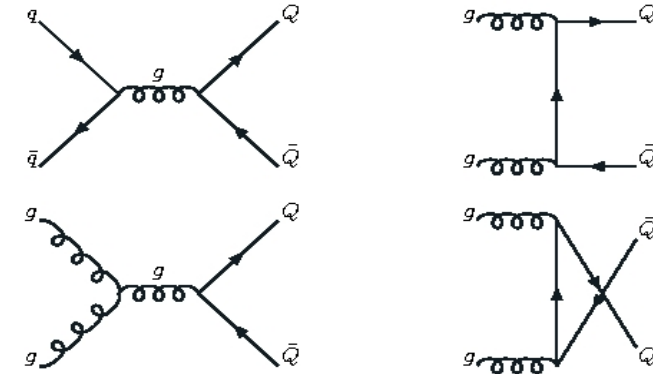
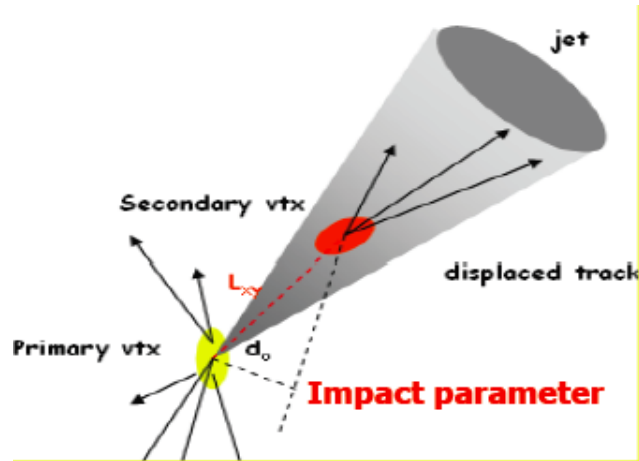


LO dominated by collinear topologies

NLO closer to the data
(region around π requires soft gluons...)

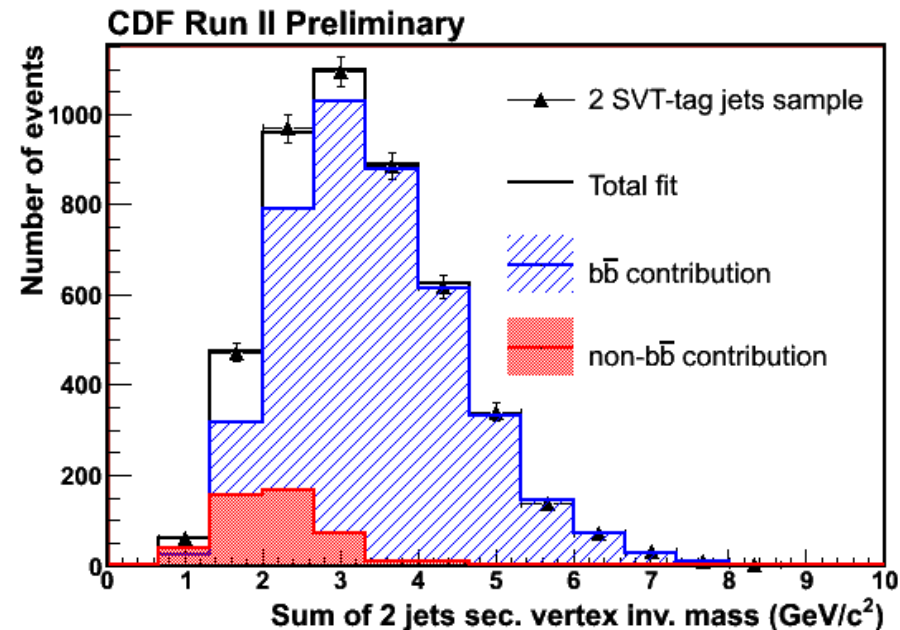
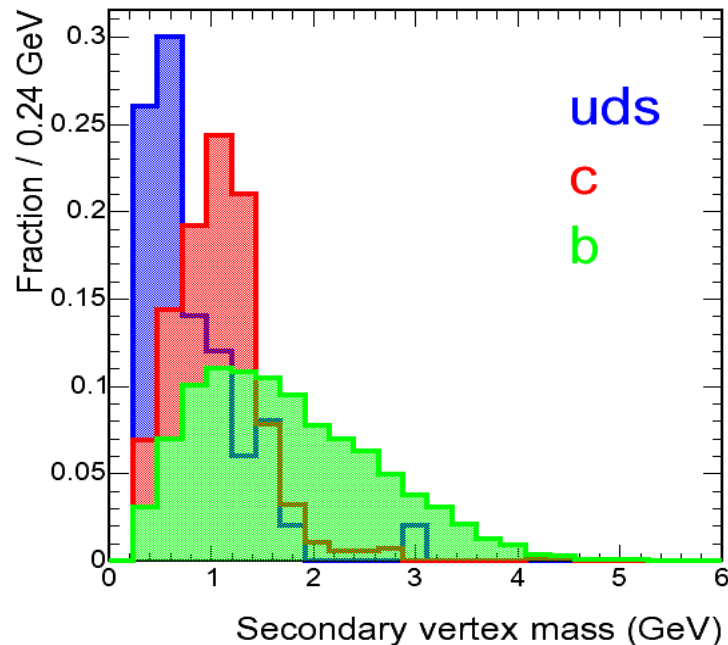
Sensitive to implementation of ISR
of soft gluons in parton shower MCs

Dijet Production ($b\bar{b}$)

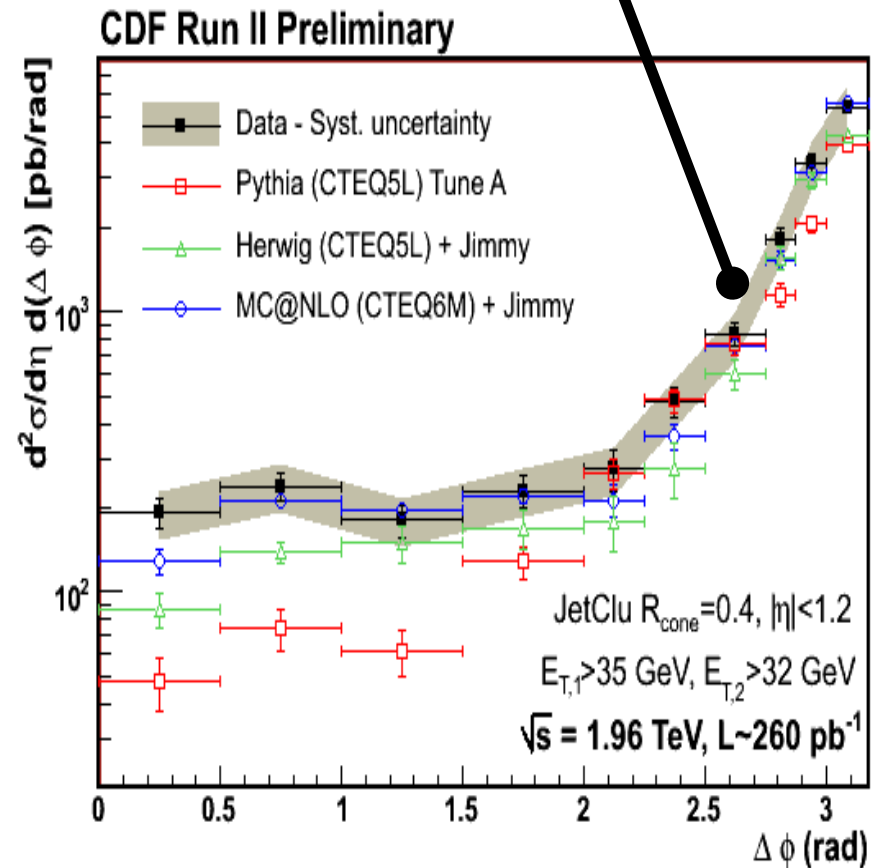
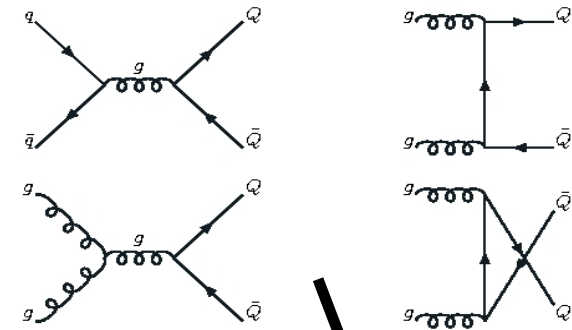
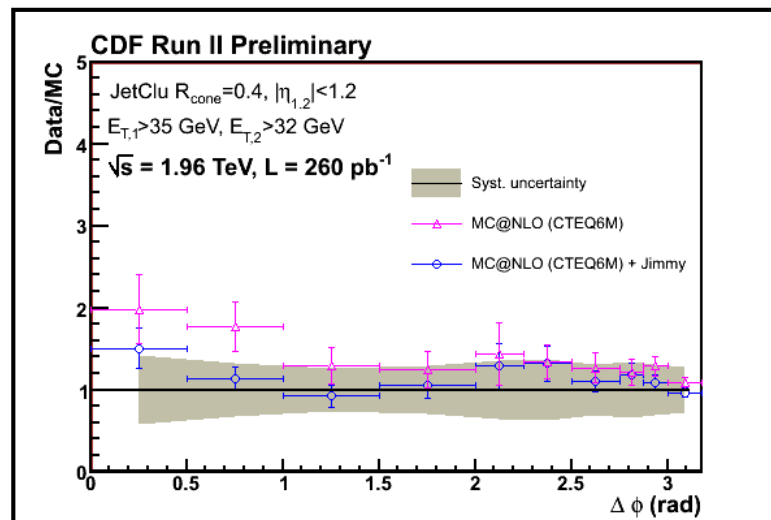
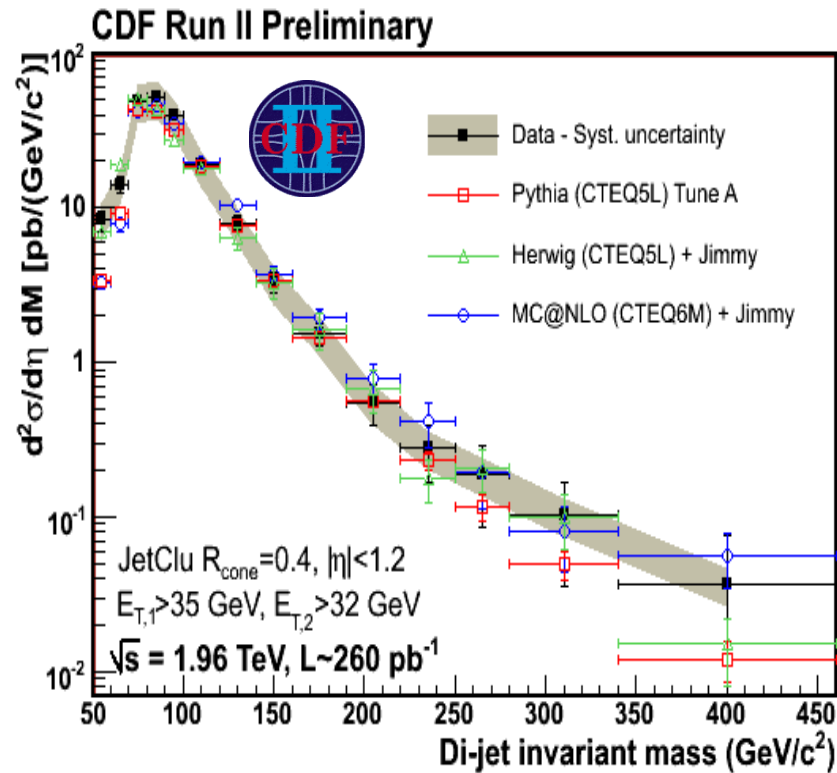


2 jets with $E_T > 35$ (32) GeV and $|\eta| < 1.2$
Identified secondary decay vertex (b-tagged)

Secondary vertex mass used to separate
bottom from (uds + c) contributions



Dijet Production ($b\bar{b}$)



NLO prediction closest to the data
(once again one needs UE contribution to bring NLO predictions to the data)



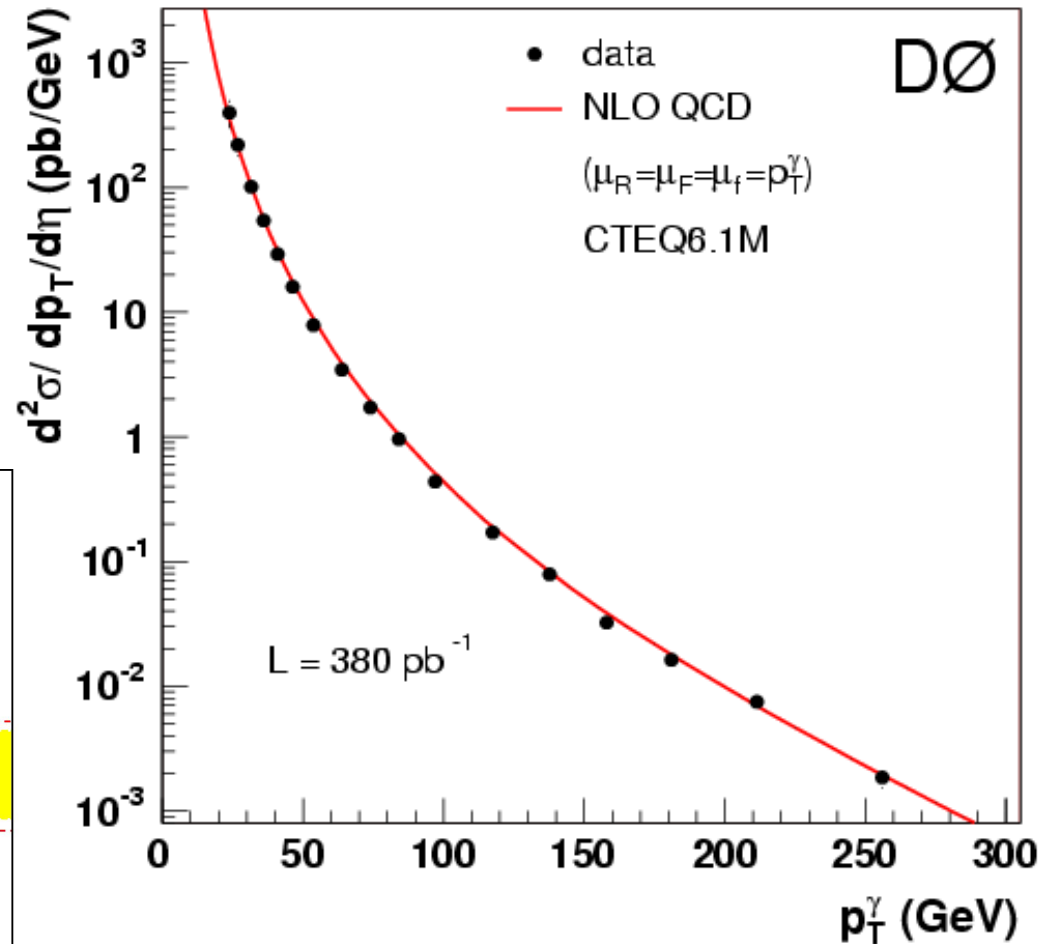
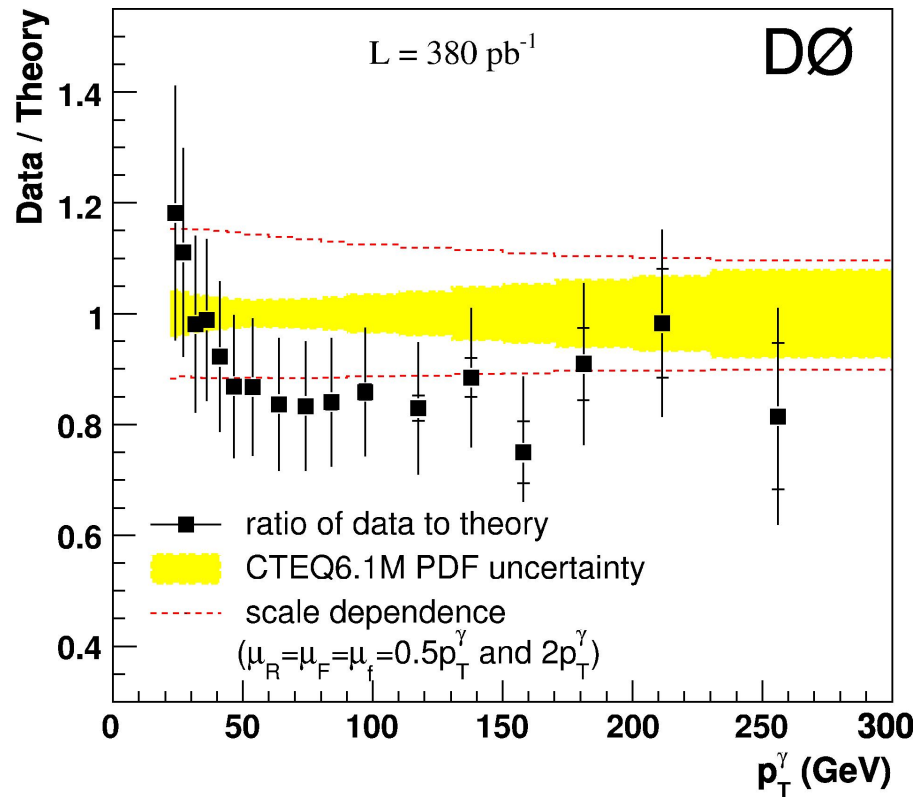
P_T^γ Distribution

PLB 639, 151 (2006)

Isolated photons

$P_T^\gamma > 23 \text{ GeV}/c$, $|\eta| < 0.9$

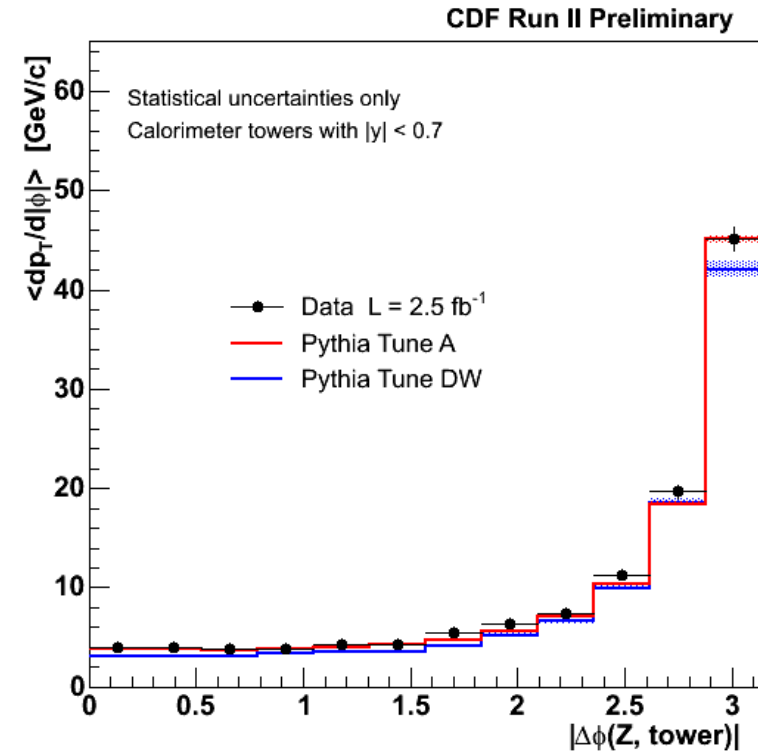
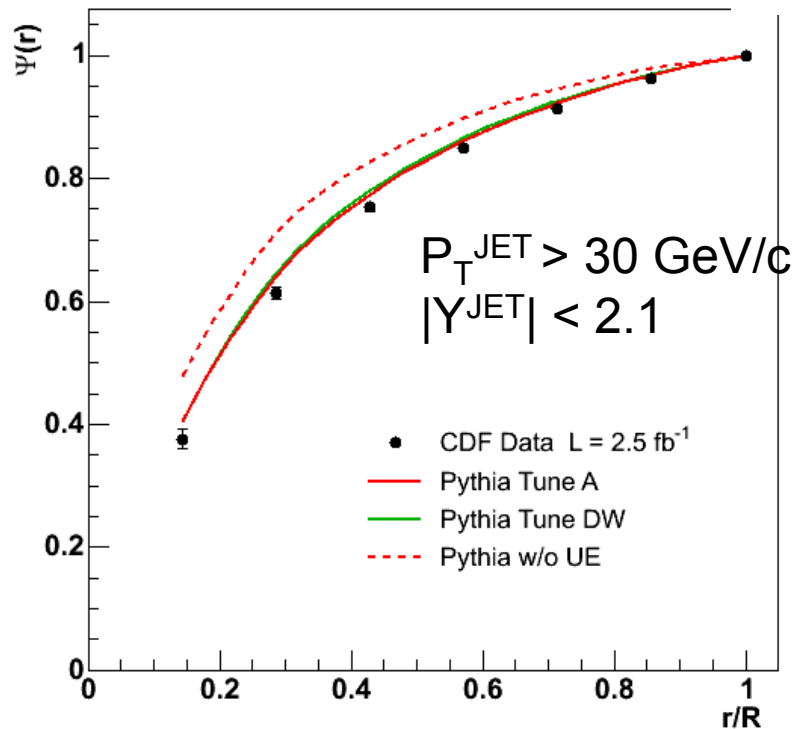
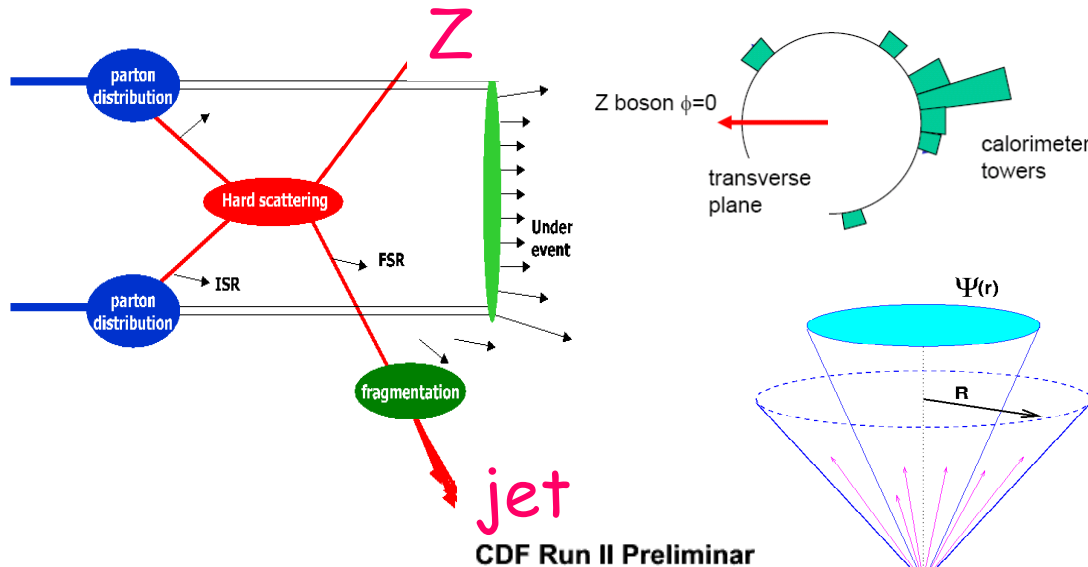
Photon signal extracted using a NN



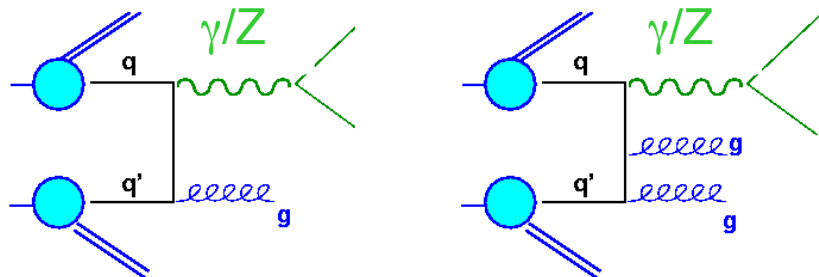
Agreement with NLO pQCD
"within quoted systematic uncertainties"

(the shape at low P_t not quite followed by the theoretical predictions)

Soft radiation in Z+jet(s)

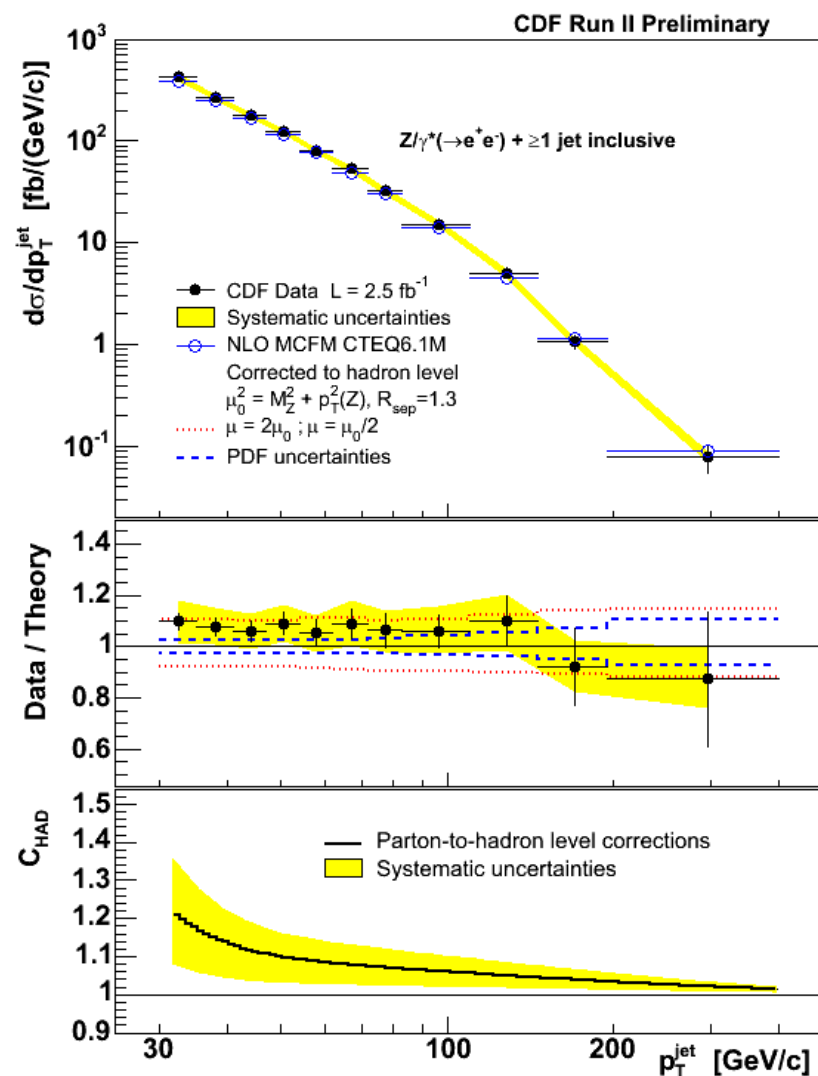
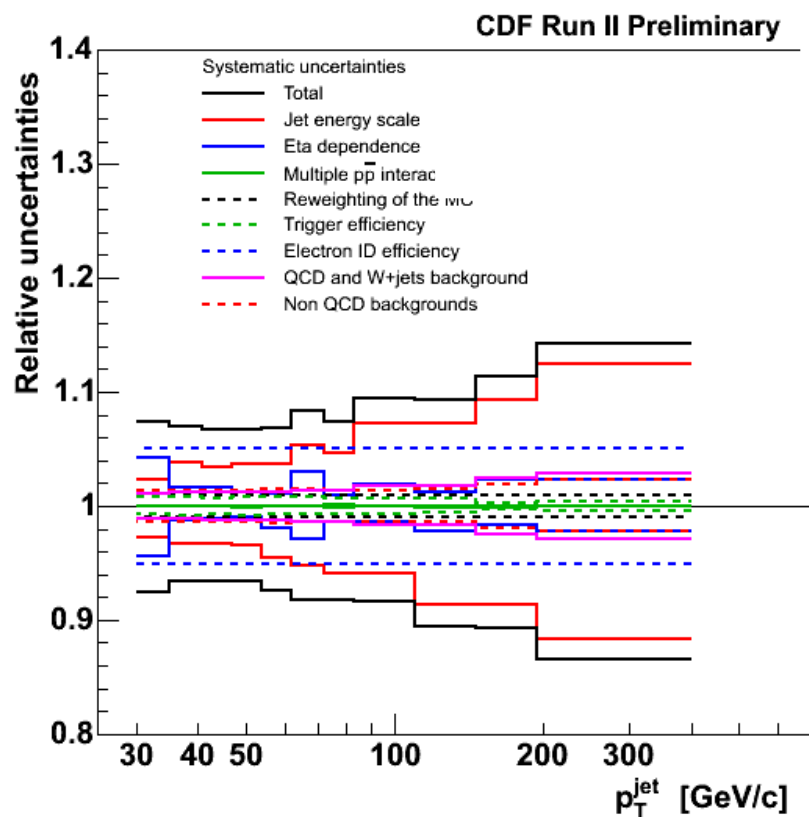


Pythia Tunes A/DW give a reasonable description of the jet shapes and energy flows in Z+jet(s) final states

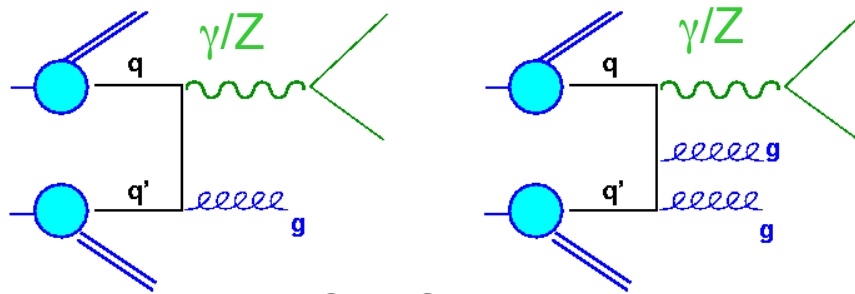


Inclusive $Z/\gamma^*(-\rightarrow ee) + \text{Jet}$

8% to 15% accuracy in the measurement
(dominant Jet Energy Scale uncertainty)



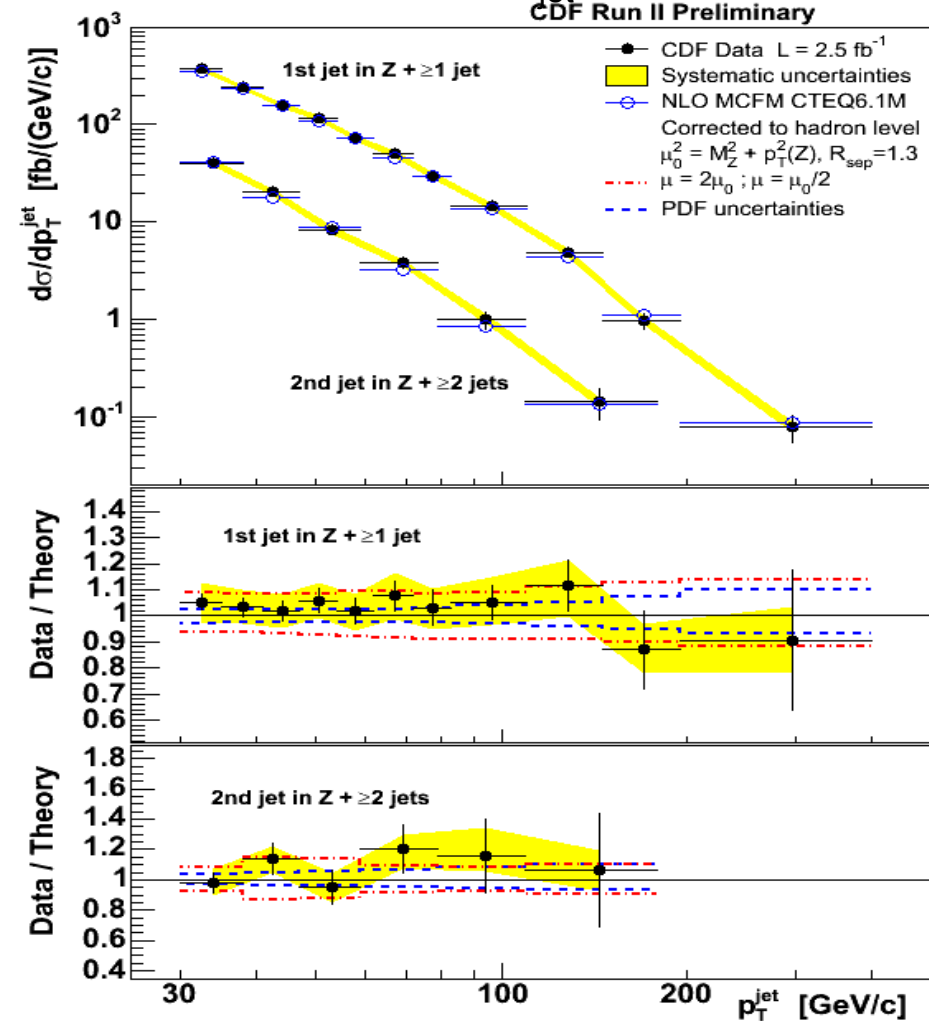
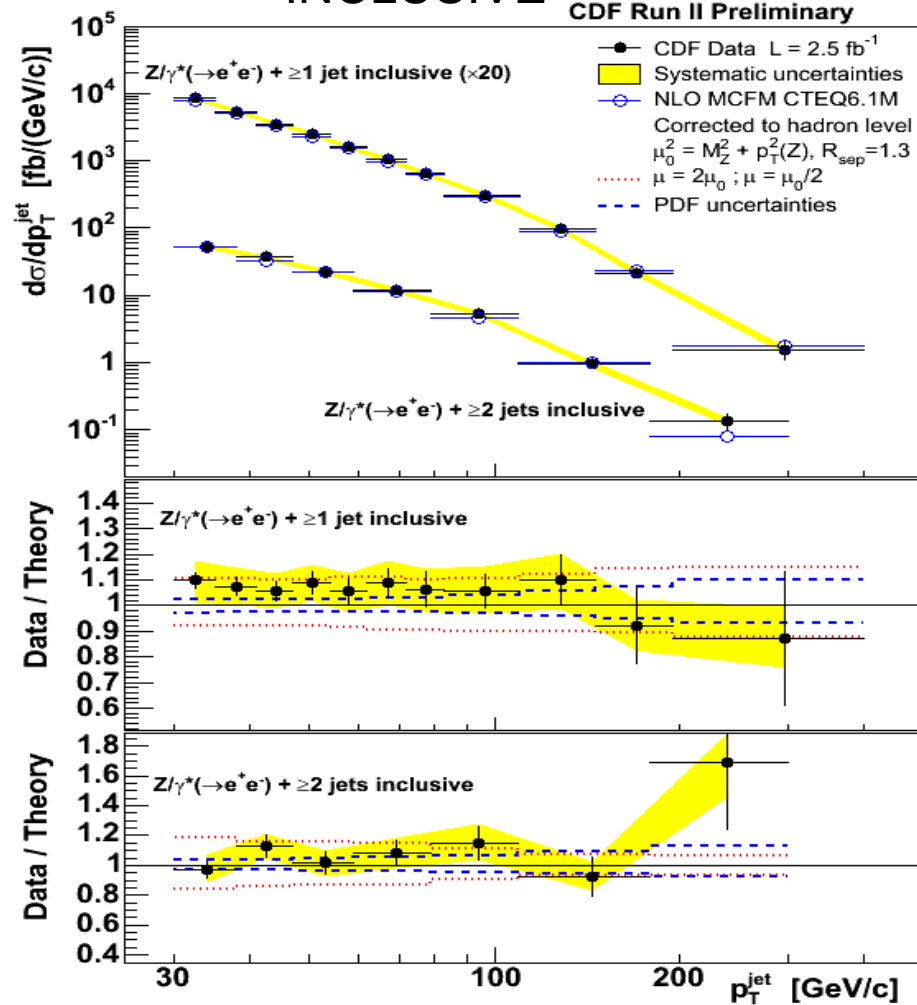
Good agreement with NLO pQCD (MCFM)
predictions including non-pQCD corrections



$Z/\gamma^*(-\rightarrow ee) + \text{jet}(s)$

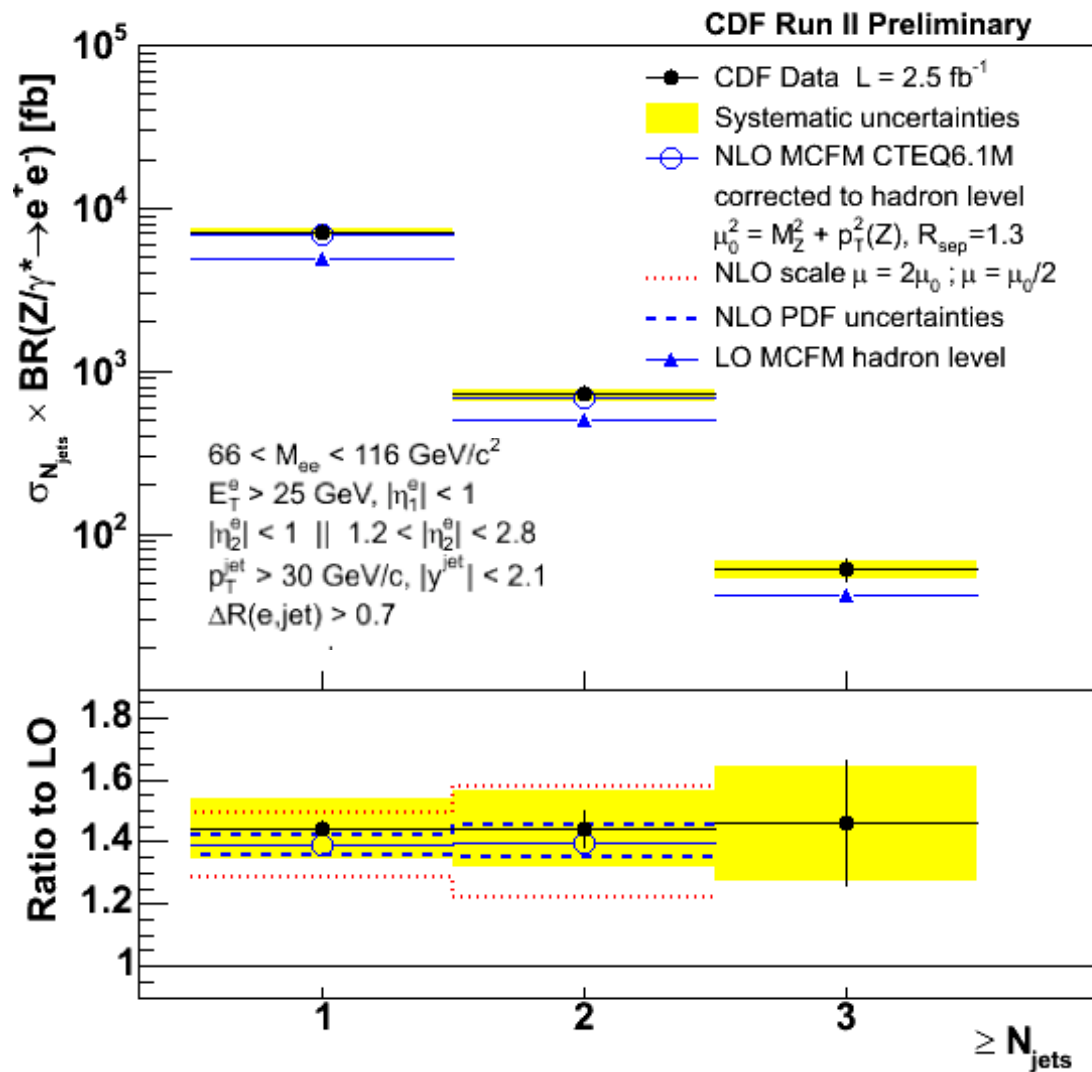
INCLUSIVE

N^{th} Jet in incl. $Z + N_{\text{jet}}$

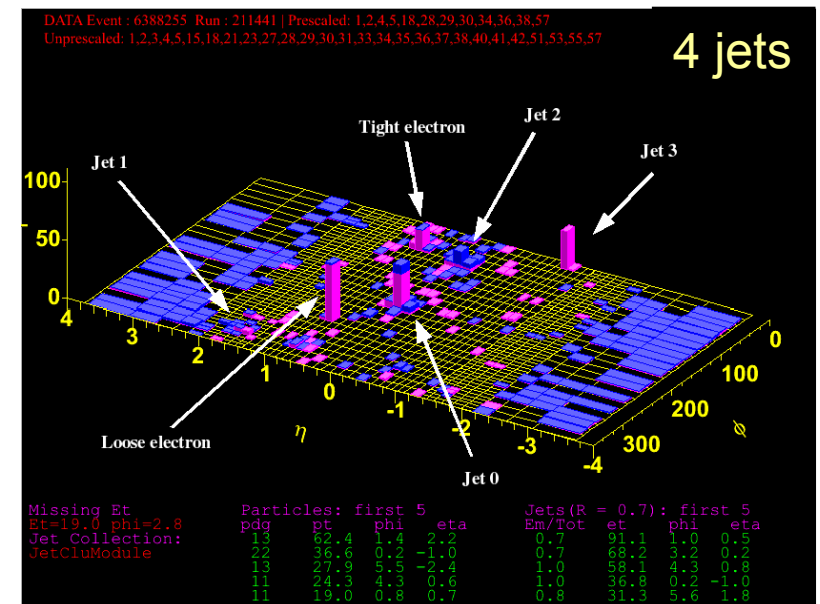
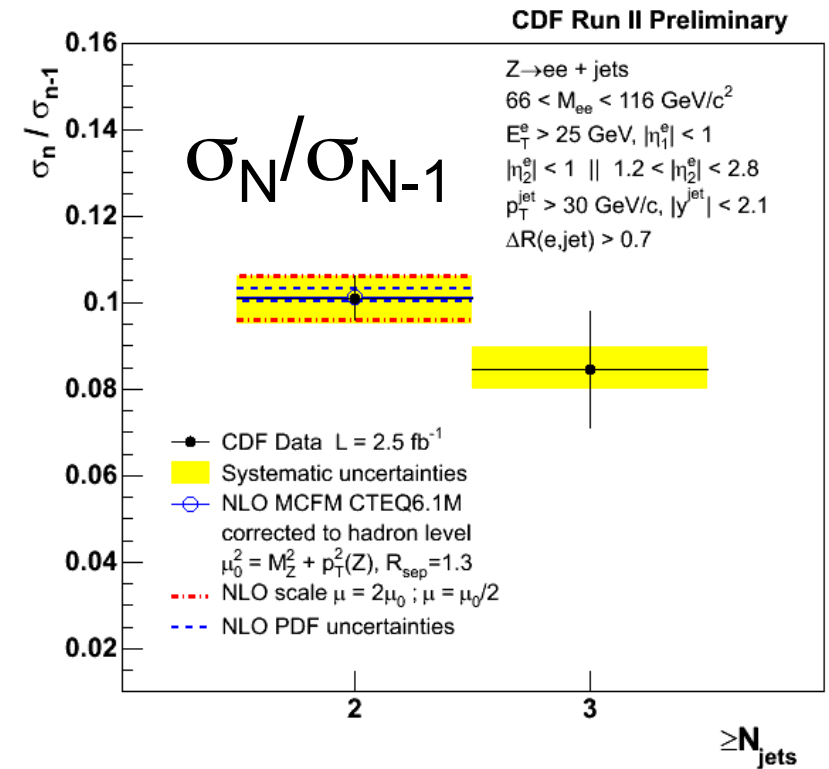


Good agreement with NLO pQCD predictions

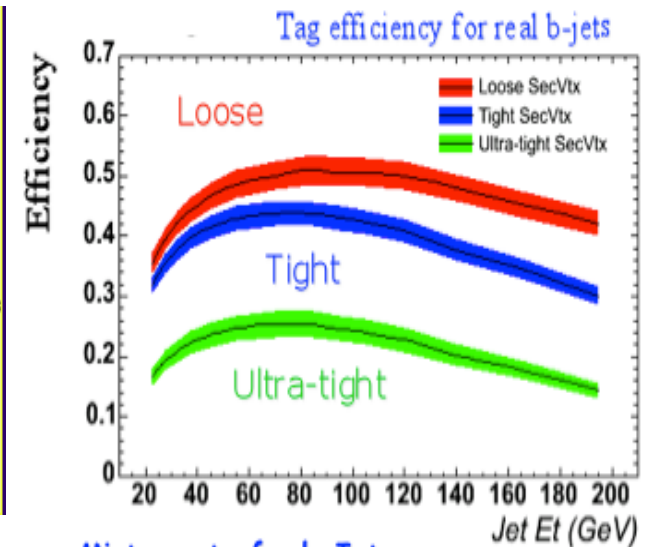
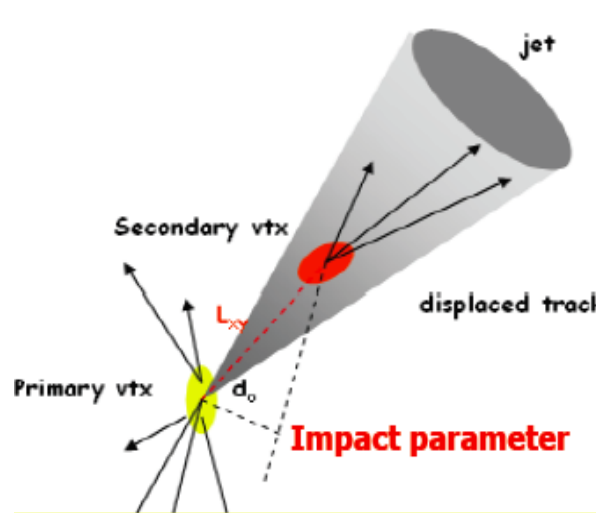
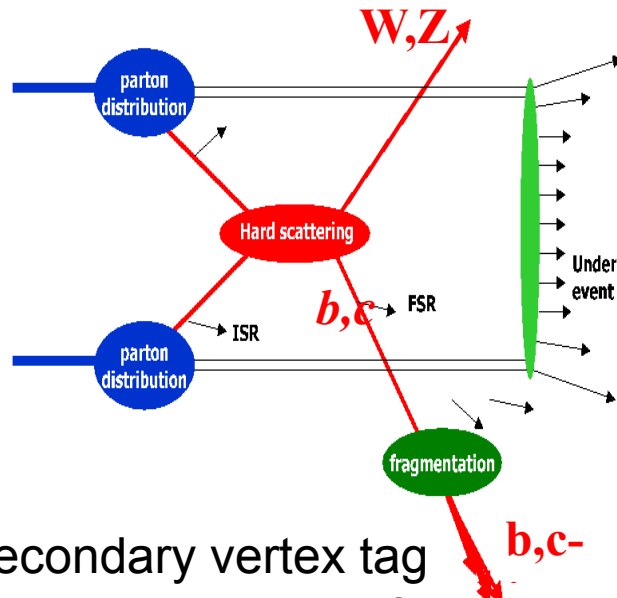
Inclusive Jet Multiplicity



Data supports common LO-to-NLO K-factor
(note potential limitation due to $\Delta R(e, \text{jet}) > 0.7$)

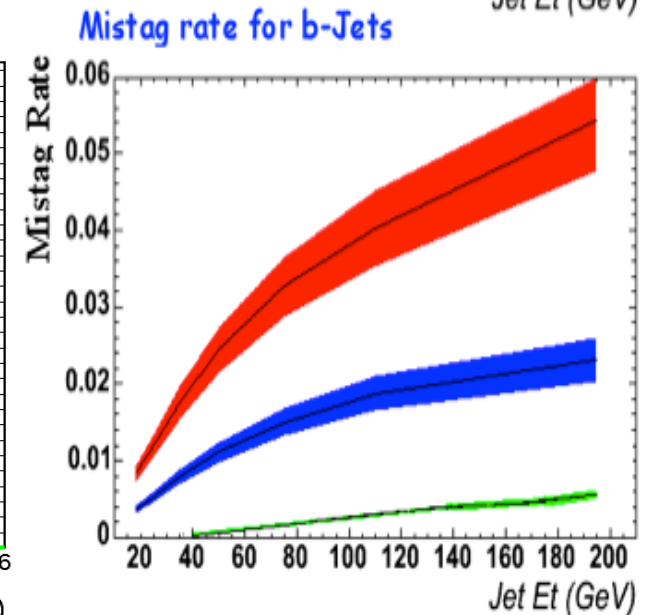
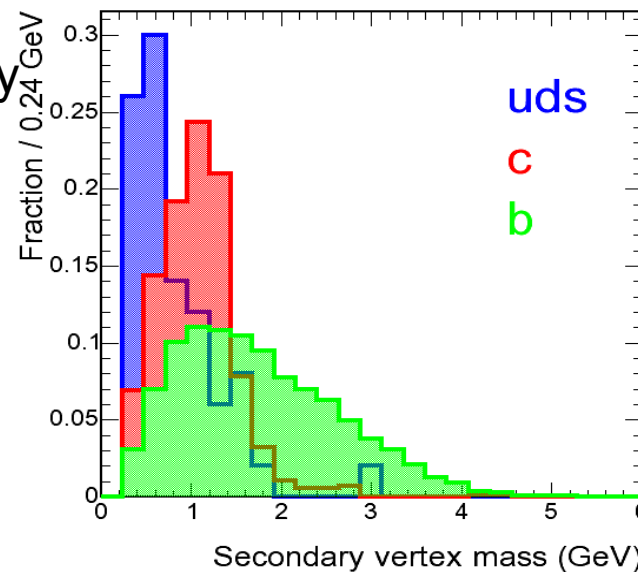


Boson + HF & B-tagging



Secondary vertex tag
(based on large B lifetime)

- 3 operating points in efficiency and purity (loose/tight/ultra-tight)
- Secondary vertex mass used to separate light from c and b quarks



Soft Lepton Tag
(20% Branching ratio...)



Main uncertainties from templates definition,
b- tag efficiencies and mistag rates